

Internet of Things and Advanced Application in Healthcare



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Internet of Things and Advanced Application in Healthcare

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Background on Context-Aware Computing Systems..... 1

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Samiha Brahimi, University of Constantine 2, Algeria

This chapter is consecrated to provide background information that encompass the basic concepts of context-aware pervasive computing systems. The major challenges that researchers need to consider when conducting research in context-aware pervasive computing systems and the most interesting approaches that can be used in order to deal with these challenges are reviewed. This chapter describes also the basic design principles of context-aware pervasive systems and depicts different models for representing and reasoning upon contextual information and an overview of the most known development frameworks of context-aware systems and application adaptation is presented too. Moreover, this chapter describes the usefulness of using context-awareness in ubiquitous healthcare domain and the major challenges in using context-awareness in this domain. The well-known works that have been proposed in the field of Ubiquitous healthcare are discussed too.

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The Internet of Things and Assistive Technologies for People with
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Hwa Lee, Bradley University, USA

With the Americans with Disabilities Act (ADA), the past two decades have seen a proliferation of Assistive Technology (AT) and its enabling impact on the lives of people with disabilities in the areas of accessing information, communication, and daily living activities. Due to recent emergence of the Internet of Things (IoT), the fields of rehabilitation, healthcare, and education are challenged to incorporate

the IoT applications into current AT services. While IoT applications continue to be developed and integrated into AT, they are still at a primitive stage where clear guidelines are yet to be developed and benefits are yet to be substantiated to ensure the quality of lives of people with disabilities. This chapter provides an overview of the IoT and AT integrated applications based on the building blocks of the IoT, along with recent trends and issues relevant to accessing technology for people with disabilities.

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Luigi De Russis, Politecnico di Torino, Italy

Alberto Monge Roffarello, Politecnico di Torino, Italy

Research activities on healthcare support systems mainly focus on people in their own homes or nurses and doctors in hospitals. A limited amount of research aims at supporting caregivers that work with people with disabilities in assisted living facilities (ALFs). This chapter explores and applies the Internet of Things to the ALF context. In particular, it presents the design, the implementation, and the experimental evaluation of Care4Me, a system supporting the daily activities of assistants. The requirements for designing and implementing Care4Me derive from a literature analysis and from a user study. The solution combines wearable and mobile technologies. With this healthcare support system, caregivers can be automatically alerted of potentially hazardous situations. Furthermore, inhabitants can require assistance instantly and from any point of the facility. The system was evaluated in two ways. The authors performed a functional test with a group of professional caregivers, and deployed the system in an ALF in Italy, collecting the opinions of caregivers and inhabitants.

Chapter 4

Hybrid Integration Technology for Wearable Sensor Systems 98

Li Xie, Thin Film Electronics ASA, Sweden

Lirong Zheng, Royal Institute of Technology, Sweden

Geng Yang, Zhejiang University, China

Personalized and pervasive healthcare devices help seamlessly integrate healthcare and wellness into the daily life, independent of time and space. Silicon Integrated Circuit (IC) has been used in many advanced healthcare applications due to the compact size and ultra-low power consumption. Meanwhile, printed electronics (PE) is considered as a promising approach enabling cost-effective manufacturing of thin, flexible, and light-weight devices. A hybrid integration of IC and PE provides a new solution for the future wearable healthcare devices. In this chapter, firstly a

customized bio-sensing IC is demonstrated, which can detect and process various bio-signals; secondly, the feasibility and performance of using inkjet printing technology as enabling technology has been examined for the fabrication of flexible bio-sensing devices. Finally, a wearable and flexible Bio-Patch is presented by leveraging hybrid integration of PE and bio-sensing IC. In-vivo test results show that the flexible Bio-Patch provides high quality ECG signal comparable with the one gained by bedside ECG machine.

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 Ilze Black, Queen Mary University of London, UK
 Graham White, Queen Mary University of London, UK

This chapter discusses the emergence of the Internet of Things, using a case study of a citizen science initiative, focusing in particular on issues involved in measuring air quality. The core of the citizen science initiative was formed by a world-wide network of early adaptors of the Internet of Things who, motivated by public health issues, set out to create widely available tools for air quality measuring. With these tools, they established a global, citizen-led, air quality measurement network. Besides highlighting a number of social and technological issues which are involve any such enterprise, this chapter engages with the discourse surrounding the use of IoT in collective sensing projects. Two questions are salient here. Firstly, can IoT technology be used in a citizen science context to monitor air quality? And secondly, does the construction of these devices lead to a successful mobilisation around issues of air quality?

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Air quality has been a recurrent issue in recent years since it can seriously impact citizens' health and their life quality. Nowadays, the different ways to provide end users with air quality information do not provide real-time data and lack accessibility. Besides, they do not automatically adapt to the particular circumstances of each citizen. In this chapter, an event-driven service-oriented architecture is proposed for detecting air quality changes in real time as well as making this information available to end users in a user-friendly way, notifying them with customized alerts upon detecting any potentially hazardous level for their health, thereby helping to prevent health risks.

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Lambert Spaanenburg, Comoray AB, Sweden

As the biological processes in the body change constantly, comparable measurements should be taken simultaneously in time and place. In practice, this is hard to achieve. Synchronicity is required to certify medical accuracy for a new device by reference to a certified one. In a typical health IoT, synchronicity cannot be enforced procedurally and timing needs to be part of the network architecture. Popular examples are in blood pressure measurement. Putting the blood flow in a known pinch-off situation performs synchronization. But this principle cannot be extended to other non-invasive measurements. Hence the chapter proposes to synchronize on basis of the heart rate extracted from the blood flow at arbitrary positions on the body. This models the blood flow in the body and relates all to the rhythm of the heart. It brings existing phenomena into a single, multi-level model that allows wireless networked wearables into a single health-monitoring scheme.

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Dulce Domingos, Universidade de Lisboa, Portugal

Ana Respício, Universidade de Lisboa, Portugal

Ricardo Martinho, Polytechnic Institute of Leiria, Portugal

BPMN (Business Process Model and Notation) has become the de-facto business process modelling language standard. Healthcare processes have been increasingly incorporating participants other than humans, including Internet of Things (IoT) physical devices such as biomedical sensors or patient electronic tags. Due to its critical requirements, IoT-aware healthcare processes justify the relevance of Quality of Services aspects, such as reliability, availability, and cost, among others. This chapter focuses on reliability and proposes to use the Stochastic Workflow Reduction (SWR) method to calculate the reliability of IoT-aware BPMN healthcare processes. In addition, the chapter proposes a BPMN language extension to provide processes with reliability information. This way, at design time, modellers can analyse alternatives and, at run time, reliability information can be used to select participants, execute services, or monitor process executions. The proposal is applied to an Ambient Assisted Living system use case, a rich example of an IoT-aware healthcare process.

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Sally A. Applin, University of Kent – Canterbury, UK

Michael D. Fischer, University of Kent – Canterbury, UK

As healthcare professionals and others embrace the Internet of Things (IoT) and smart environment paradigms, developers will bear the brunt of constructing the IT relationships within these, making sense of the big data produced as a result, and managing the relationships between people and technologies. This chapter explores how PolySocial Reality (PoSR), a framework for representing how people, devices and communication technologies interact, can be applied to developing use cases combining IoT and smart environment paradigms, giving special consideration to the nature of location-aware messaging from sensors and the resultant data collection in a healthcare environment. Based on this discussion, the authors suggest ways to enable more robust intra-sensor messaging through leveraging social awareness by software agents applied in carefully considered healthcare contexts.

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Cristina Elena Turcu, University of Suceava, Romania

Corneliu Octavian Turcu, University of Suceava, Romania

This chapter presents a future vision for healthcare, which will involve smart devices, Internet of Things, and social networks, that make this vision a reality. The authors present the necessary background by introducing the Social Internet of Things paradigm. Agent technology seems to be a promising approach in the adoption of the Social Internet of Things in collaborative environments with increased autonomy and agility, like healthcare is. Also, it is examined challenges to the adoption of the Social Internet of Things in healthcare in order to facilitate new applications and services in more effective and efficient ways.

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Preface

The National Intelligence Council (National Intelligence Council, 2008) predicted that “everyday things” such as food packages, furniture, and paper documents will have their own internet nodes by 2025. And, according to Cisco, by 2030 there will be 500 billion connected devices to the Internet (CISCO, 2016).

The Internet of Things (IoT) will allow people and things to be connected anytime, anyplace, with anything and anyone, ideally using any path or network, and any service. This can and will be accomplished through a worldwide network of interconnected objects uniquely addressable, based on standard communication protocols (Atzori, Iera, & Morabito, *The Internet of Things: A survey*, 2010). Advances in the underlying technology are providing opportunities for new applications to evolve and, at the same time, their widespread use, is generating concerns that are quite distinct from the ones currently addressed on the Internet, namely the ones regarding security issues (Sundmaeker, Guillemin, Friess, & Woelfflé, 2010; Gubbi, Buyya, Marusic, & Palaniswami, 2013).

IoT aims to improve the quality of human life by automating some of the basic tasks that humans must perform. Creating and deploying smart objects allows offices, homes, industrial plants or even leisure environments to become “intelligent” and smart environments. These smart environments and spaces and self-aware things will largely contribute to the improvement of the general population’s healthcare and wellbeing (Miller, 2015).

As the IoT continues to develop, new opportunities that result in applications for the healthcare domain can be grouped into tracing and tracking of objects and people (ubiquitous identification of patients, health professionals, equipment and medicine), identification and authentication of people, automatic data collection and sensing (continuous communication improvements) (Islam, Kwak, Kabir, Hossain, & Kwak, 2015), among others.

Technology is changing and improving industry, with a significant potential and impact in healthcare. An extension of these emerging new approaches is tracking, which identifies a person or object in motion. For instance, patient identification enables an adequate and updated electronic medical record and allows for the re-

duction of harmful incidents such as wrong drug, or dose, or procedure. Sensors and multiple wireless technologies will enable real-time information monitoring on patient health indicators. Currently they can be applied to both inpatient and outpatient care, reaching for patients when in mobility and ensuring personalized medicine (Baldauf, Dustdar, & Rosenberg, 2007). Whereas, automatic data collection aims to reduce the amount of form processing time and process automation.

In fact, IoT proposes assisted living scenarios where sensors support the monitoring environment to ensure that both patients and the elderly have the desired life quality (Rashidi & Mihailidis, 2013; Calvaresi, et al., 2016). Furthermore, solutions that include wearables enables people to call for immediate assistance and provide real-time data collection. This is becoming a fashion trend that will be able to improve health quality and wellbeing (Gatzoulis & Iakovidis, 2007; Hiremath, Yang, & Mankodiya, 2014).

Heating systems that adapt to custom preferences and to weather conditions, energy savers that switch off electrical equipment when they are not needed, improve our wellness and well-being. In the last decades, air quality issues are gaining exposure and the overall population is more conscious of the burden and health impact of the air pollution (World Health Organization, 2016; Kullenberg & Kasperowski, 2016).

On the other hand, spending some leisure time at a museum or at the gym is an experience that can be improved with the use of IoT. This also relates to the personal and social domain where you establish and maintain relationships with friends. The potential impact that IoT has in our everyday life must be measured in terms of personal needs and social interaction (Atzori, Iera, Morabito, & Nitti, 2012).

ORGANIZATION OF THE BOOK

The book is organized into 10 chapters. A brief description of each of the chapters follows:

Chapter 1 reviews context-aware pervasive computing systems and ubiquitous healthcare systems. Smart systems include smart devices that need to adapt themselves automatically in response to a dynamic change of context. Some key challenges in the subject are presented and include topics such as context acquisition, modelling and reasoning, amongst others. The basic principles behind the design of such systems are presented, including several models for representing and reasoning upon contextual information and some frameworks specifically used for context-aware applications.

Chapter 2 analyzes the impact of current IoT in the current proliferation of Assistive Technology (AT). Some clear guidelines and the specific benefits to ensure the quality of lives of people with disabilities are yet to be developed and integrated

in existing and future applications. Furthermore, recent trends and issues relevant to accessing technology for people with disabilities, are provided.

Chapter 3 presents Care4Me, an Assisted Living Facility (ALF) system, that supports the daily activities of caregivers that work with people with disabilities. This solution combines wearables with mobile technologies, and enables inhabitants to call for immediate assistance (anywhere and at any time) and provides automatic alerts of potential hazardous situations to assistants. Care4Me was assessed in the field, both by professional caregivers and inhabitants of an ALF in Italy.

Chapter 4 reviews the current wearable healthcare systems. Furthermore, the authors present existing customized integrated circuits (IC) for bio-sensing and distinct printed electrodes (PE) available nowadays. Then, a hybrid integration of flexible circuits, joining bio-sensing IC with PE assumes the shape of a Bio-Patch, whose implementation is provided. This wearable and flexible Bio-Patch provides an accurate electrocardiography (ECG) signal, similar to the one measured by a bedside machine.

Chapter 5 provides a case study of a citizen science initiative that uses the Internet of Things (IoT) to measure air quality. The citizen's network is formed by early adopters of the IoT that created tools available for measuring air quality. Several issues regarding motivation, data reliability and accuracy, and the effective use of the results are provided to question the success of this type of citizen mobilization around public health concerns.

Chapter 6 also approaches the air quality issue bringing it to the next level. By designing an integrated system that has an architecture that includes IoT as the data source, uses Complex Event Processing (CEP) and a Service Oriented Architecture (SOA) to detect certain event patterns and send real-time alerts to the interested parties. A case study uses simulated sensors, made available through ThingSpeak, then published through a Mule Enterprise Service Bus (ESB) application that converts them into events sent to Esper, the CEP engine responsible for the real-time alerts.

Chapter 7 introduces one of the major concerns regarding IoT: synchronicity. Particularly in healthcare contexts, synchronicity is fundamental to certify medical accuracy when considering a new device. The chapter presents a model to measure blood pressure, using the heart rate collected from arbitrary positions on the body, and then relating the data to the rhythm of the heart. Thus, allowing wireless network wearables to become a single health-monitoring scheme.

Chapter 8 analyzes the reliability of services provided in healthcare contexts and introduces an extension to the Business Process Model and Notation (BPMN) that provides reliability information to healthcare processes. Thus, designers of IoT based systems are able to make informed decisions and choose from a set of alternatives, using reliability information to select participants, execute services or

monitor process executions. The proposal is applied to an Ambient Assisted Living system, with an IoT-aware healthcare process.

Chapter 9 depicts a framework that represents how people, devices and communication technologies can interact, the PolySocial Reality (PoSR) framework. Developing systems that include IoT and smart environment paradigms, with location-aware messaging from sensors, can be ease by the direct application of this framework. In specific healthcare contexts, leveraging social awareness of software agents allows a more robust intra-sensor messaging.

Chapter 10 presents the Social Internet of Things (SIoT) paradigm and its application to the healthcare context. Through the usage of multi-agent technology, it is possible to develop a new generation of applications where the human-to-device social relationship is explored. A description of a specific condition, asthma, is presented to show how the access to exact and real-time information enable patients to be more aware of their close environment. Thus, with SIoT it becomes possible to address several challenges to improve efficiency in healthcare.

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Thank you.

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Chapter 1

Background on Context–Aware Computing Systems

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ABSTRACT

This chapter is consecrated to provide background information that encompass the basic concepts of context-aware pervasive computing systems. The major challenges that researchers need to consider when conducting research in context-aware pervasive computing systems and the most interesting approaches that can be used in order to deal with these challenges are reviewed. This chapter describes also the basic design principles of context-aware pervasive systems and depicts different models for representing and reasoning upon contextual information and an overview of the most known development frameworks of context-aware systems and application adaptation is presented too. Moreover, this chapter describes the usefulness of using context-awareness in ubiquitous healthcare domain and the major challenges in using context-awareness in this domain. The well-known works that have been proposed in the field of Ubiquitous healthcare are discussed too.

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INTRODUCTION

Nowadays, with Ambient Intelligence paradigm (AmI)(Marzano, 2003) we are surrounded by a multitude of embedded and smart devices, including sensors, actuators, smart phones, tablets, cameras, etc. which interact and exchange information using wireless communication technology. This paradigm involves the fields of ubiquitous/pervasive computing (Weiser, 1991) and context awareness (B. N. Schilit & Theimer, 1994). The later has been recognized as an important characteristic of pervasive systems where a multitude of smart devices and sensors collects data, interact, exchange information and provide various significant services in our life (Agoston, Ueda, & Nishimura, 2000): controlling our home, monitoring our health, alerting in case of dangerous conditions, assisting us in driving, supervising our children on their way to school, organizing our shopping lists and taking care of time-tabling. Context-aware applications are becoming increasingly more prevalent and can be found in the areas of wearable computing, mobile computing, robotics, adaptive, intelligent user interfaces, augmented reality, adaptive computing and intelligent environments. Implementing a context-aware system requires addressing many issues still faced with enormous challenges in both research and practice. The most interesting challenges are: How to acquire context, how to represent context, and how to reason upon context. Also, the adaptation to the changing computing and networking environment is a major challenge. Besides, the complexity of this kind of systems is steadily increasing.

Ubiquitous or pervasive healthcare (U-Healthcare) (J.-H. Kim et al., 2009) represents one of the main application areas of pervasive computing that provides several services; such as monitoring health and wellbeing of patients anytime and anywhere by using intelligent environment technologies. With the progress of ubiquitous technologies, it is becoming possible to provide more smart and pervasive healthcare services in a smart home environment. These services allow patients to live safely and independently in their own homes. In order to provide such services, those systems must be able to learn about their environment over time, and react rapidly even if they encounter a new situation in which behavioural adaptation is required. This means that they have to adapt their behaviour to the dynamic change of context. In computer science, this kind of concern is known as “context-awareness”.

This chapter provides background information regarding the most important aspects related to the context-aware pervasive computing and ubiquitous healthcare systems. Several definitions existing in literature for both pervasive computing systems and context-aware computing systems are given in the second section. The third section presents an overview of the most important challenges facing the design and the development of this kind of systems. In the same section, well-known works related to this field are discussed. Finally the last section concludes the chapter.

Pervasive/Ubiquitous Computing

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

These words were written by Mark Weiser, in his paper “The Computer for the 21st Century” (Weiser, 1991) in order to describe his new vision of an embedded computing world. Within this world computers would be an invisible part of our everyday lives; and computing was going to change from desktop, personal computing to a more distributed, mobile and embedded form.

Weiser and his colleagues have used the terms “ubiquitous” and “pervasive” computing to describe their vision.

What Do the Terms ‘Pervasive’ and ‘Ubiquitous’ Mean?

Although in computer science community and among the scientists, ubiquitous computing and pervasive computing are used interchangeably, there is a nuance between them.

Ubiquitous means “existing or being everywhere”, while pervasive means “spread throughout”¹.

In computing terms, those seem like somewhat similar concepts. Ubiquitous computing would be everywhere, and pervasive computing would be in all parts of your life. According to (McCrory, 2000), pervasive computing involves devices like small handhelds, easy-to-use devices, through which we will be able to get information on anything and everything. That’s the sort of thing that Web-enabled cell phones promise. Ubiquitous computing, though, eschews our having to use computers at all. Instead, it is computing in the background, with technology embedded in the things we already use. That might be a car navigation system that, by accessing satellite pictures, alerts us to a traffic jam ahead, or an oven that shuts off when our food is cooked.

According to (Dillon, 2006), ubiquitous computing is best considered as the invisible underlying framework, the embedded systems, networks and displays found everywhere, allowing us to ‘plug-and-play’ devices and tools. Pervasive computing, on the other hand, would be all the physical parts of our life; our mobile phone, hand-held computer or our smart jacket, which changes with our body temperature. Pervasive computing therefore refers to the distributed set of tools within our environment, through which we access information anytime and anywhere.

As (Weiser, 1991), the authors of this chapter consider that “Pervasive computing” and Ubiquitous computing” refer to the same thing, so those terms are used interchangeably.

Many aspects of Weiser's visions have already become reality in the past two decades. Furthermore, one of his primary ideas has recently evolved into a more general paradigm known as context awareness. Detailed information about context-aware computing is given in the following section.

Context-Aware Computing

Context-aware computing is a mobile computing paradigm in which applications can discover and take advantage of contextual information such as user location, time of day, neighbouring users and devices, user activity, and user environment (Musumba & Nyongesa, 2013).

The notion of context-awareness has been recognized as an important characteristic of pervasive systems where a multitude of smart devices and sensors collect data, interact and exchange information and provide several services. The concept of context-awareness has increasingly gained importance in the area of distributed systems since the 90's. Since that, it seemed to be a promising solution for a lot of problems engendered by the use of mobile terminals in ever-changing environments (Tahir, 2013).

Context and Context-Awareness

Several definitions are proposed for the terms "context and context-aware computing".

Schilit and Theimer were first to define context and context-awareness (in their 1994's paper (B. N. Schilit & Theimer, 1994)) as the ability of applications to discover and react to changes in the environment (i.e., location, identity of people, nearby devices, and objects) they are situated in. Two months later, (B. Schilit, Adams, & Want, 1994) stated that context has three important aspects consisting of responses to the questions: *Where are you? Who are with you? And what resources are nearby you?* They define context as constantly changing environment of people, places, and devices. They defined context-aware application as an application that changes or adapts its behaviour dynamically, based on the context of application and user.

In 1998, Dey (Dey, Abowd, & Wood, 1998) initially defined context as any information about the user and the environment that can be used to enhance the user's experiences. This included data such as: the user's physical, social, emotional, or informational state. (Abowd et al., 1999) have defined a context as any information that can be used to characterize the situation of an entity (person, place or object), that is considered relevant to the user, the application and the interaction between the user and the application. They have also defined a context-aware system as follows: "a system is context-aware if it uses context to provide relevant information and / or services to the user". (Miraoui & Tadj, 2007) proposed a service-oriented

Background on Context-Aware Computing Systems

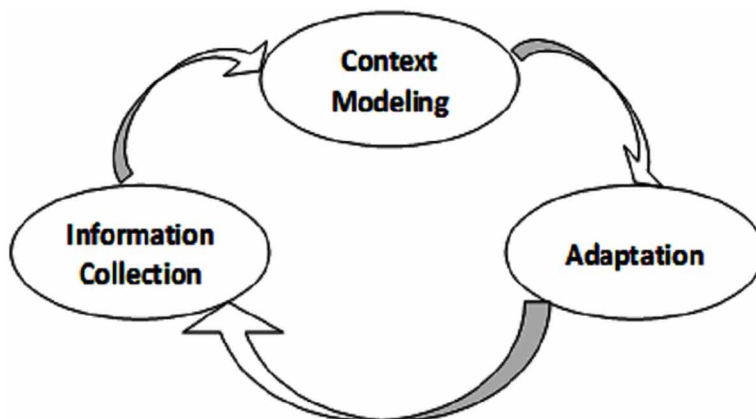
definition of context for a pervasive computing system as follows: “Any information that triggers a service or changes the quality of a service if its value changes.” Furthermore, the latter authors affirmed that: “A system is said to be context-aware if it can automatically change the form of its services or can provide a service in response to the change in the value of information or a set of information that characterizes those services”.

The authors of this chapter conclude that the terms “context and context-awareness” do not have a precise definition, each author defines them based on his proposed work. Nevertheless, they all agree that the context-awareness consists mainly in collecting information, modelling the context, and making the necessary adaptation, which present one of the most challenges in the field of context-aware pervasive systems (see Figure 1). More details are given in the next section.

Key Challenges in Context-Aware Pervasive Computing

Implementing a context-aware system requires addressing many issues still faced with enormous challenges in both research and practice. In (Xu, 2013), (Malik, Mahmud, & Javed, 2007) and (Kang & Pisan, 2006), authors have discussed the major challenges that researchers need to consider when conducting research in context-aware computing and the difficulties in developing a promising system. The most interesting challenges are: *How to acquire context information?* *How to model context information?* *How to reason upon context information?* and *How to provide the most attractive services?* Also, the adaptation of applications and services to changing computing and networking environment is a major challenge.

Figure 1. The main phases for context-awareness



Context Acquisition

To be able to use context in applications, there must be a mechanism to sense the current context and provide it to the application. Context acquisition is the first process for all context-aware systems. It refers to an ability to detect contextual information from diverse context sources, including heterogeneous physical sensors/devices and software entities that provide raw data from the device or the environment to the system. Generally, the context is detected through the sensors that are locally built into the mobile devices or presented in the environment and is gathered by the acquisition modules of the context-aware systems. The data generated by the sensors are dynamic and voluminous. By analyzing raw data acquired from sensors, devices and services can recognize the context of a user, and surrounding environment (Yamabe, Takagi, & Nakajima, 2005).

In ubiquitous computing environments, there are a variety of kinds of context with different data formats. Therefore, context acquisition process requires understanding what type of contextual information the sensors provide, communicating with context sources by diverse communication protocols: HTTP, REST, SOAP, etc. The extracted raw data will be dispatched to different parts for further processing at a later stage. Moreover, it is very important that context-based systems filter any unnecessary information (redundant information) to allow for more effective use of context information or more effective operations of the system as more relevant information can be put together.

Context Modelling

One of the greatest challenges of context-aware computing is modelling context information. The raw data cannot be employed directly by context-aware systems since it is obtained from various heterogeneous context sources, and has their own expressions and models (Xu, 2013). Therefore, it requires an approach that can define and organize context in order to be understood by the systems. The context model is in charge of representing and organizing context. It allows representing and storing context data in a machine processable form (Baldauf, Dustdar, & Rosenberg, 2007). Owing to the diversity of context sources, providing a uniform and extensible context model is needed to facilitate the other component of context-aware systems to access and handle context. It is a fundamental design question how to most appropriately design a model for a pervasive computing system being able to capture and encapsulate a large amount of information in the environment. Finding the answer of the question is quite important, because such a model provides computational support for constructing, describing, implementing, and analyzing the patterns of the interaction and coordination among context (Kang & Pisan, 2006).

Context Reasoning

Context-aware systems can be executed on light-weight systems such as mobile phones or sensor nodes, and they have to react within milliseconds when detecting a context (Schmidtke, 2012). The key idea of using context data and being able to react to the context in an intelligent way, often referred to context reasoning, is one of the most challenging contemporary research task. Context reasoning, also known as context inference, is one of the crucial parts of context processing that has a brain-like role, designed to automatically infer high-level, implicit context requested by context-aware intelligence services from related, low-level, explicit context (Xu, 2013). The high-level context is defined as the context that cannot be directly extracted from the context source.

Context reasoning also may play the role of a decision making mechanism (Bikakis, Patkos, Antoniou, & Plexousakis, 2007). Based on the collected context information, the system can be configured to change its behaviour, whenever certain changes are detected in its context. It is therefore important that the context modelling techniques must be able to support reasoning techniques. These techniques can be used to derive new context facts from existing context facts and/or reason about high-level context abstractions that model real world situations (Bettini et al., 2010). The reasoning techniques should be computationally efficient.

Providing the Most Attractive Services

In (Kang & Pisan, 2006), authors have considered that providing the most attractive services to the users is one of the pervasive systems challenges. In fact, pervasive computing is a user-centric view of computing. This means the best services must be supported to all the users in a pervasive environment. Further, those services should not be contradicted with user preferences. For example, if the dynamic configuration is not consistent with user preferences, the user may be confused or surprised by that change. User preferences are invisible and seamlessly shift over time, it is a significant challenge. User has different preferences or makes different decisions about the same context. This implies that a particular user might intrude or distract other's preferences intentionally or accidentally.

Adaptation of Mobile Applications and Services

Finally, adaptation to changing computing and networking environment is also very important in the ubiquitous computing systems (Varshney, 2009). In these systems, users use devices that have different set of computing and communication resources. For context-aware applications running on mobile devices, it is vital to deal with the dynamically changing environments and to efficiently exploit the context information within limited resources of the device and mobile communication system. Applications will need to adapt continuously to highly dynamic operating environments, heterogeneous device capabilities, and limited resource availability. When

deployed on a low-end device, they often need to adapt to smaller screen sizes, less powerful processors or low bandwidth. Applications and services require a modular design that supports runtime adaptation and reconfiguration. This design should make explicit what functional variations are possible in the composition: i.e. what the deployment constraints are for each component in the composition and how components should be reconfigured for a given context. Runtime support is needed in order to facilitate the dynamic reconfiguration of applications and consistency checking to avoid conflicting adaptations among two or more simultaneously running applications (BERBERS & PREUVENEERS, 2009).

Design Principles of Context-Aware Pervasive Systems

In this section, authors describe the basic design principles of context-aware systems and depict different models for representing and reasoning upon contextual information. An overview of the most known development frameworks of context-aware systems and application adaptation is presented too.

Architecture of Context-Aware Systems

Context-aware systems can be implemented in many ways (Baldauf et al., 2007). The architectural style and design is usually dependent on special requirements and conditions such as the location of sensors (local or remote), the amount of possible users (one user or many), the available resources of the used devices (high-end-PCs or small mobile devices) or the facility of a further extension of the system. Furthermore, the method of context-data acquisition is very important when designing context-aware systems because it predefines the architectural style of the system at least to some extent.

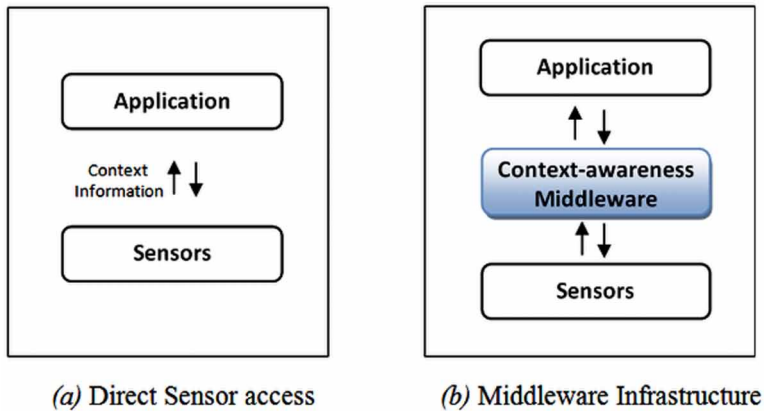
Generally, context information can be acquired through two different approaches (Baldauf et al., 2007):

1. *Direct Sensors access* without any additional layer for processing sensor data, or
2. *Middleware Infrastructure* that encapsulates low-level sensing details (see Figure 2).

Compared to direct sensor access, middleware infrastructure technique eases extensibility since the client code does not have to be modified anymore and it simplifies the reusability of hardware dependent sensing code due to the strict encapsulation. Direct sensor access is not suited for distributed systems due to its direct access nature which lacks a component capable of managing multiple concur-

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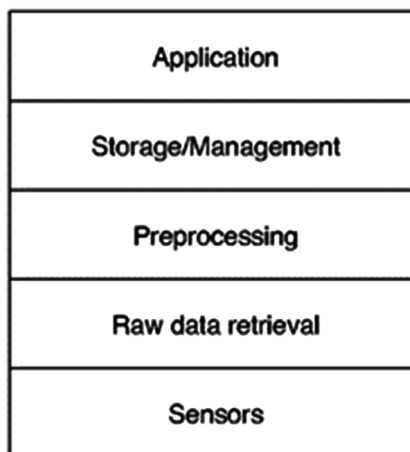
Figure 2. Context acquisition approaches



rent sensor accesses. Thus, a separation of detecting and using context is necessary to improve extensibility and reusability of systems.

Several design architectures for context-aware systems have been evolved during the last years. Most of them differ in functional range, naming layers, and the use of optional agents or other architectural concerns. In (Baldauf et al., 2007), authors have analyzed a various design approaches, and a common layered conceptual architecture in modern context-aware applications is presented. From the functional viewpoint, context-aware systems can be represented as a layered framework (see Figure 3), composed from bottom to top of sensors, raw data retrieval, pre-processing, storage or management, and an application layer.

Figure 3. A sample layered context-aware framework
Source: Baldauf et al., 2007.



The first layer consists of a collection of different sensors. It is notable that the word ‘sensor’ not only refers to sensing hardware but also to every data source which may provide usable context information. These sensors can be classified in three categories: *physical sensors*, *virtual sensors*, and *logical sensors*. The most frequently used sensors are physical sensors which are capable of capturing almost any physical data, such as thermometers, bio-sensors, cameras, microphones, etc. Unlike physical sensor, virtual sensors capture context data from software applications or services. For example, the user’s activity is a context data that can be sensed by checking the mouse-movement and keyboard input. Logical sensors combine information from physical and virtual sensors with additional information from databases or other sources in order to make other information. For example, a logical sensor can be constructed to detect an employee’s current location by analyzing logins at desktop PCs and magnetic card readers.

The second layer is responsible for the retrieval of raw context data by using specific application programming interfaces or protocols to request data from the sensor layer. The third layer, *Pre-processing*, is responsible for reasoning and interpreting contextual information. In context-aware systems consisting of several different context data sources, the single context atoms can be combined to high-level information in this layer. This process is also called ‘*aggregation*’ or ‘*composition*’.

The fourth layer, *Storage and Management*, organizes the gathered data and makes them available to the application and stores them for later use. This storage can be centralized or distributed (Chaari, 2007). The centralized solution is the most common and most used option since it facilitates the management of updates and changes in context values. The distributed management context is much more complex since it inflicts additional functions resource discoveries and updating context of values.

Finally, the *Application* layer presents applications that offer significant services and functionalities to the customer, where the necessary reactions to context changes are implemented (e.g. displaying text in a higher colour contrast if illumination is bad). Each application subscribes to the previous layer in order to access different contextual information and be informed of any change. Applications may access information in two different ways, synchronous and asynchronous. In case of synchronous access, the application requests context information from the previous layer. This is usually accomplished by remote method calls. In case of asynchronous communication, the application subscribes to specific events that correspond to changes in context values. Once an event is triggered, the application is notified using call-back functions.

Existing architectures do not give more details about the *Application* layer. The realization of this layer depends on the application area whereas services are really dependent on the needs of the application users.

Context-Awareness Models

Developing context-aware systems in pervasive context-aware computing should be supported by adequate context information modelling and reasoning techniques (Bettini et al., 2010). These techniques reduce the complexity of those systems and improve their maintainability.

Several researchers working in the area of pervasive and context-aware computing have developed different kinds of context models and each model brings along some reasoning techniques. In this section the authors present the most interesting context modelling approaches in the literature (Strang & Linnhoff-Popien, 2004), (Bettini et al., 2010) and (Nalepa & Bobek, 2014). These models are: Key-value models, Mark-up scheme models, Graphical models, Object oriented models, Logic-based models, Spatial models, Ontology-based models and Rules model.

Key-Value Models

Key-value models represent the simplest data structure for modelling context information as a couple (attribute, value) which allows providing contextual data to applications in the form of variables. The key is usually a name that defines a context property. For instance, it can denote location (e.g. room) or time (e.g. day-time). The value represents current state of the context property (e.g. kitchen, etc.). These models are easy to implement but they are not convenient for complicated structure and do not allow a good reasoning on the context. The reasoning is usually supported by a simple matching engine. When the keys match the actual context values, an action is triggered. The inference is supported usually by a very simple matching algorithm that does not allow a more sophisticated reasoning form (Nalepa & Bobek, 2014). The key-value model is used in early context-aware systems, such as (B. Schilit et al., 1994).

Markup Scheme Models

Markup scheme models are based on XML and use hierarchical data structure consisting of markup tags with attributes and content. *Profiles* are typical representatives of this kind of context models. They usually base upon a serialization of a derivative of Standard Generic Markup Language (SGML), the super class of all markup languages such as the popular XML. The Composite Capabilities/Preference Profile (CC/PP) (W3C, 1999) and User Agent Profile (WAPFORUM, 2001) which are encoded in RDF/S are the most used profiles. Compared with the key-value models, the markup scheme models provide a better context representation and can be used in structured and distributed computer systems. However, they have

difficulty in describing the complex relationships between contextual information, and lack an effective resolution mechanism for processing incomplete, dynamic contextual data. In addition, they have limited capabilities on supporting reasoning on context, context uncertainty and higher context abstractions.

Graphical Models

Graphical models are also used to model the context due to their generic structure. They use graph-oriented modelling tools; such as UML (Unified Modelling Language) and ORM (object-relational mapping); to describe contextual information (Sheng & Benatallah, 2005). These models are intuitive and have powerful presentation skills for relational databases in information management systems. They are simple but less formal than the Markup scheme models.

Object-Oriented Models

Common to object oriented context modelling approaches is the intention to employ the main benefits of any object oriented approach namely: encapsulation and reusability, and to represent contextual information. The context details are encapsulated in objects and the object provides methods to access the contextual information. A representative for this kind of models is the *cues* (Schmidt, Beigl, & Gellersen, 1999) developed within the TEA project (Schmidt & Van Laerhoven, 2001). Object oriented models require low level execution agreements between applications to ensure interoperability. They are not adapted for knowledge sharing in open and dynamic environments.

Logic-Based Models

Logic-based models define context as a set of facts, expressions and rules. Usually contextual information is added too, updated in and deleted from a logic-based system in terms of facts or inferred from the rules in the system respectively. One of the first logic-based context modelling approaches has been published as Formalizing Context by McCarthy and his group at Stanford (MCCARTHY, 1993). In general, logic-based models adopt a higher formal representation. They are often based on a centralized context management, which are not adapted to the principle of context distribution in a pervasive computing. The relations between continuous data cannot be easily described.

Spatial Models

Spatial context models are well suited for context-aware applications that are mainly focused on location-based scenarios, like many mobile information systems (Topcu, 2011). These models are based on the organization of context information by physical location, including the location of the real world entities which is described in the context information, or the location of the sensor that measures the context information (Bettini et al., 2010). They allow also reasoning about the location and the spatial relationships of objects. In addition, the use of spatial organizations in mobile systems would help to manage their large amount of context information where relevant context information can be easily preselected by using a spatial predicate (Bettini et al., 2010).

Ontology-Based Models

Ontology-based models use ontology to represent contextual information and relationships between context information. These models are the most comprehensive on the degrees of expression of information and its semantics. Their high and formal expressiveness can be used to describe complex context data that cannot be represented, for example, by simple languages like CC/PP (Strang & Linnhoff-Popien, 2004). Ontology-based models adopt the formal representation of knowledge domains, support reasoning tasks in a better way than many other modelling approaches. In addition, they can import the other existing ontologies for reuse of knowledge. They also provide a good sharing of information with common semantics. In addition, most context modelling approaches are realized for a special application scenario and on that account many context information models are limited from the view of interoperability. Ontology-based context modelling can be used for different context-aware applications (Topcu, 2011).

Rule-Based Reasoning

In the Ambient Intelligence domain, rules are primarily used to express policies, constraints and preferences. Rule languages provide a formal model for context reasoning. They are easy to understand and widespread used. In addition, they allow for more complex reasoning than just a simple classification tasks provided by ontological approaches (Nalepa & Bobek, 2014). However, they cannot handle the highly changeable, ambiguous and imperfect context information (Bikakis et al., 2007).

Principal Existing Context-Aware Development Frameworks

In the last decade, various platforms and middleware to support context-aware development have been developed in the literature. They adopt different architectural approaches mainly driven by the context acquisition, different methods of context representation and context reasoning.

In this section the most interesting context-aware frameworks (Context Toolkit, CoBrA, and SOCAM) are shortly described.

Context Toolkit

The Context Toolkit, developed by Dey (Dey, 2000), is a toolkit supporting the development of context-aware applications. The Context Toolkit provides a set of abstractions that can be used to implement reusable components for context sensing and interpretation. The toolkit enables application developers to build context-aware applications. This work has pioneered in proposing generic support for context-aware application development by means of a conceptual framework. It adopts the key-value pairs (encoded using XML for transmission) context modelling, and has storage support. In addition, the Context Toolkit can be used as a research test platform, supporting more complex studies of context-awareness, such as the development of high-level abstract programming, processing of unconcerned context information, and accessing control of user's context information.

Context Broker Architecture: CoBrA

CoBra (Chen, Finin, & Joshi, 2003) is an agent-based architecture for supporting the development of context-aware applications in so-called intelligent spaces (physical places-meeting rooms, homes, corporate offices, and vehicles, populated with intelligent systems that provide pervasive computing services to the users). Central to this architecture is the presence of an intelligent context broker that maintains and manages a shared contextual model on behalf of a community of agents. These agents can be applications hosted by mobile devices that a user carries or wears (e.g., cell phones, PDAs and headphones), services provided by devices in a room (e.g., projector service, light controller and room temperature controller) and web services that provide a web presence for people, places and things in the physical world (e.g., services keeping track of peoples and object whereabouts). It adopts ontology to model context information, which is suitable for knowledge sharing and high-level context reasoning. Compared with the Context Toolkit, CoBrA provides better support for knowledge sharing and context reasoning using a common ontology defined using Semantic Web languages (Chen et al., 2003).

Service-Oriented Context-Aware Middleware (SOCAM)

The Service-Oriented Context-Aware Middleware (SOCAM) is an architecture that enables the building and rapid prototyping of context-aware services in pervasive computing environments, developed in 2005 by (Gu, Pung, & Zhang, 2005). SOCAM provides efficient support for acquiring, discovering, interpreting and accessing various context to build context-aware services. SOCAM uses ontologies for context modelling and reasoning, as it aims at converting physical spaces into semantic ones.

SOCAM is similar to CoBrA, because it also aims to build a middleware for context-aware services and uses OWL to model its context, but SOCAM goes further than CoBrA. The context model proposed in SOCAM is designed on two hierarchical ontology layer which are common upper ontology for general concepts and the domain-specific ontology for different sub-domains.

Application Fields of Context-Aware Systems

The application areas of context-aware systems are primarily smart spaces where users can interact with each other and traditional systems using their mobile devices. As technology advances and context-awareness computing evolves, the number of areas where context-awareness is applied increases. Following some of them are listed (Hristova, 2008):

- **Airports:** Emergency response solutions are based on context-aware systems which can automatically deliver immediate security alerts to the relevant personnel at the airport, such as: security, maintenance, fire department, police etc. Services directly aimed to passengers, that are closely connected to the location of the passenger are developed as well. They adapt the notifications that are sent to the passengers' mobile devices depending on the users' location and inform them about shopping zones nearby, exits, gates, arrivals and departures.
- **Smart Homes:** Context-awareness integrated with technology and services through home networking increases the quality of living and can help disabled or elderly people lead safe and independent lives in their homes. It can provide:
 - **Security Functions:** Generation of alerts in case of fire, gas leakage, open tap, detection of unknown persons present in the home. These alerts are sent to the user as graphical or audio information, but can be directly sent to the appropriate institution as well e.g. police, fire department etc.

- **Appliances Functions:** Monitoring and control of the appliances in the household such as turning on/off the light, opening/closing the window, turning on/off the air conditioner and heater, improving energy management etc.
- **Environmental Information:** Overview of the situation in the domicile and the environmental parameters in each room.
- **Healthcare Functions:** Constant monitoring of the person's biomedical functions, sending reminders about daily tasks he needs to perform e.g. medication intake and sending alerts to remote caregivers if an emergency situation is detected.
- **Museums and Fairs:** Context-awareness is closely related to detecting user's position in a building and guiding them through it. It is commonly used to run applications on portable devices which are location sensitive and provide audio and video information to the user about art pieces in a museum or a gallery, give directions about the way to reach a specific place of interest during a fair, etc.
- **Offices:** Usual services that can be found beneficial in office work is locating the position of employees in the company building, additional information about the office where they are located (whether there is a meeting in progress, how many people are present), environmental parameters measured in the office where a user is present, inferring the activity of the user depending on pending calendar entries, etc.
- **Hospitals:** Context-awareness can aid in improving the quality of service in hospitals by implementing interactive hospitals where doctors and nurses are provided information about the diagnosis, the treatment and medical history of patients in their proximity and they are able to carry out video conferences which enable collaborative feedback, discussion and diagnosis with other doctors. These interactive hospitals would also support reminders to patients for medication intake, verification that the nurse is carrying the right medicine, closely monitor the patient's state and raise emergency alerts if necessary, carry out video conferences between a doctor and a patient at home, etc.

Ubiquitous or pervasive healthcare (U-Healthcare) represents one of the main application areas of pervasive computing. It provides several services; such as monitoring health and wellbeing of patients anytime and anywhere by using intelligent environment technologies. More details about this application domain are given in the following section.

Ubiquitous Healthcare

In recent years, interests in U-healthcare which monitors man's health conditions and provides specialized healthcare services whenever and wherever it is needed, have been increased. The U-healthcare stands for Ubiquitous healthcare that provides healthcare services using remote medical technologies without any limitations in time and space (J.-H. Kim et al., 2009). U-healthcare means a system that can monitor bio-information in real-time using certain devices and mobile equipments in a home network. U-Healthcare services provide medical and healthcare services continuously and generally for the "healthy life" of customers through active participation and cooperation in all members employed in industries based on wire and wireless IT technologies through merging it to other advanced technologies. U-Healthcare can be classified as sensing, monitoring, analyzing, and alert according to the role in a system. The sensing plays a role in the sense of the physical and chemical changes in patients. The monitoring is a step that first processes the measured bio-information and plays a role in the verification of patients' information in real-time. The analyzing is a step that obtains some information from the collected data and plays a role in the figuration of the state of patients. The alert plays a role in the notification of related information to users based on the obtained information.

In fact, health monitoring has received some attention from worldwide researchers in the last few years. This has resulted in several prototypes, systems, and applications of health monitoring in a variety of scenarios, especially for elderly persons or those that have severe mental or physical limitations living alone at homes.

Information Technologies can play a major role in how healthcare services are designed, offered and utilized. There are several suitable information and communications technologies for healthcare among which we can distinguish four categories: implanted (inside human body), wearable, portable, and environmental (Varshney, 2009). The use of implanted technologies could include use of Radio Frequency Identification (RFID) and sensors inside the human body. The wearable technologies include the use of Smart Shirts, which are designed to wear for extended period of time for monitoring of health conditions. The portable devices, such as handheld computers and smart-phones, can be used in monitoring and recording health conditions. Finally, environmental technologies include adding computing and communication capabilities in the surrounding of patients such as a "Smart Home", where appliances have smartness to assist people in their daily activities. With the progress of ubiquitous technologies, more smart services can be provided in a smart home environment that allows patients to live safely and independently in their homes. Additionally, telemedicine and mobile telemedicine technologies can be used to improve the overall quality of care.

Context-Awareness in U-Healthcare Systems

Using context-awareness in ubiquitous or pervasive healthcare systems is being very useful for the following reasons (Varshney, 2009): First, there are a large number of situations and related tasks; mobility of patients, healthcare professionals and some equipments; limited financial and human resources; and the need to cut cost while improving the quality of service to an increased number of people.

In addition, the objective of using context information in a U-Healthcare environment is to provide high-quality services by inferring all possible information related to users and that should provide active and intellectual services required by users (J. Kim & Chung, 2014).

In fact, the context information may come from multiple sources such as sensors, wearable and portable computers, some databases that may have information on the patient or from patient's input in some cases. The type of information that could be collected include the type of health monitoring, vital signs, prescribed medicines, sensory information, activities, environmental variables, and patient history. The information on missing doses, recent labs, known handicaps, and unusual conditions would also be very useful in health monitoring.

Challenges in Context-Aware Pervasive Healthcare Systems

Some major challenges in using context-awareness in pervasive healthcare are (Varshney, 2009):

1. Derivation of context, which could be evolving at different rates in different healthcare services,
2. The need to adapt to changes in context as it evolves, and
3. Corrective actions when something goes wrong in a context-aware system involved in healthcare delivery.

Additionally, there are some limitations of context and context-awareness in pervasive healthcare. In some healthcare services, the description of a situation by using what (activity), who (identity), where (location) and when (time) may not be enough, where more richness and higher reliability are required. This could include how (process), with whom (source), and so what (needed action). This will either increase the complexity of context-aware system or will result in higher chance of error in the delivery of healthcare services. The increased complexity could also lead to a slower operation of systems, not desirable for some services, such as emergency services in pervasive healthcare.

Related Works

Several interesting works have been proposed in the field of U-Healthcare. The authors present here some initiatives that they consider most relevant.

Context-Aware Middleware for Personalized U- HealthCare (CAMPU)

In (Ko, Lee, & Lee, 2007) authors proposed a Context-aware system named, CAMPU, that permits to process the physical data of the user and provide suitable context to the healthcare service embedded system. They have also proposed an ontology-based context model and context reasoning for U-HealthCare in a ubiquitous environment. As shown in Figure 4, CAMPU consists of the sensing device, context-aware framework, and the applications.

The Sensing Device senses the physical raw data information of the user and then transfers the raw data to the Context Provider in the Context-Aware Framework of a PDA using ZigBee protocol. The Context Provider generates low-level context according to the context model and then delivers the low-level context to the Context Integrator. The Context Integrator integrates the context coming from the different Context Providers and selects the most suitable context among the different context providers. The integrated context is delivered to the Context Interpreter. The primary purpose of the Context Interpreter is to generate high-level context from the integrated low-level context using an inference engine. The Inference Engine uses the knowledge base and ontology to infer context.

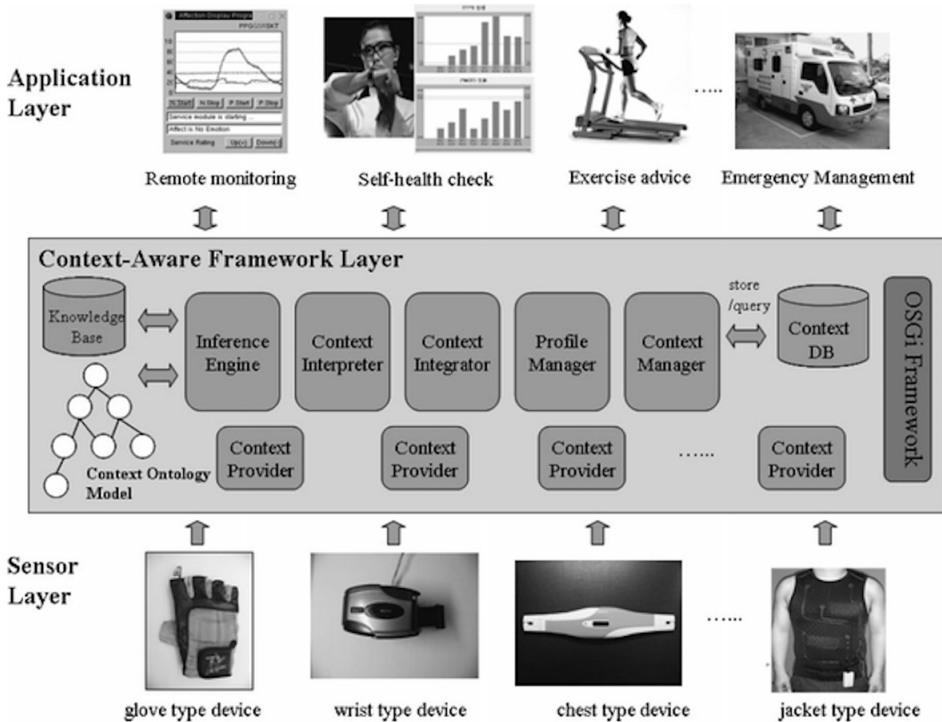
The Profile Manager manages the personal information of the user including name, age, weight, height, disease history and the normal range of the health condition. The Context Manager manages context store and context query. The healthcare service is automatically called by the context-aware framework or is selected by the user using the user interface on the PDA.

Context-Aware Rule-Based Healthcare Monitoring System

(Catarinucci, Colella, Esposito, Tarricone, & Zappatore, 2012) proposed a context-aware infrastructure for ubiquitous and pervasive monitoring of heterogeneous healthcare-related scenarios. The system is based on the integration between three core implementation choices: ontology representation, multi-agent paradigm and rule-based logic. Ontologies are used to formalize contextual information in a reusable and sharable codification. The multi-agent paradigm acts as the unifying software backbone. It provides distributed software entities capable of communicating by means of ontologies and able to reason according to a rule-based paradigm.

Figure 4. The architecture of context-aware system CAMPU

Source: Ko et al., 2007.



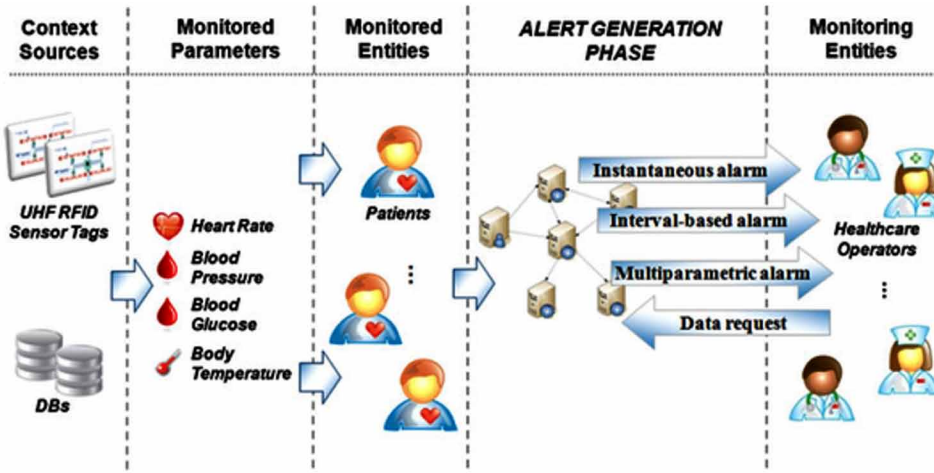
The proposed system allows patients to be continuously monitored by medical equipment. An alarm may be generated when patient data exceed some threshold. Information about patients (thresholds, history, etc.) and doctors (specialization, availability, telephone numbers, etc.) is used to identify the doctor best suited to manage an alarm situation. The doctor is alerted on his laptop/mobile and may request further information to best analyze the patient situation.

As shown in Figure 5, on one side there are data, on the other side there are the so-called monitoring entities. Data include both raw data provided by physical sources, such as RFID, biomedical sensors and data codified into virtual storage entities, such as databases, documents, etc. Raw data are associated to monitored parameters (e.g. body temperature, heart rate, etc.). Monitored entities are notified when input raw data have some out-of-range behaviour. Several monitored entities, on their side, may be aggregated to form more complex monitored entities (e.g. several patients may be grouped into hospitals). The core of the entire system is the alert notification component, which is substantially responsible for: detecting alarm events; selecting the monitoring entities being best suited to manage the alarm event when it occurs; and sending data to the monitoring entity when needed.

Background on Context-Aware Computing Systems

Figure 5. Schematic representation of alert generation systems

Source: Catarinucci et al., 2012.



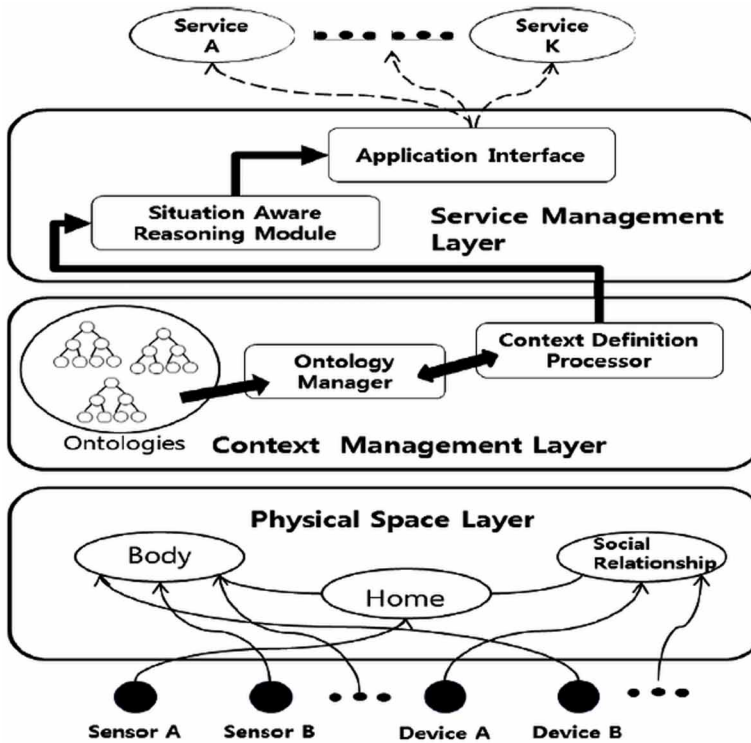
Ontology Model-Based Situation and Socially-Aware Health Care Service in a Smart Home Environment

In (Lee & Kwon, 2013), authors proposed a platform for the smart home healthcare systems that permits to: 1) handle wide range of context which generally occur in the house, 2) collect various types of sensor data and define what situations currently happen at the home space surrounding the specific user, 3) analyze historical context data and social data to recommend good health assistant services, 4) support transparent integration of a wide variety of devices to implement interoperability, remote monitoring, and remote programmability. The platform uses ontologies and rule-based approach to model context and reason upon which are generally distributed in smart home environment including person entities modelling care network members (i.e., user or patient, healthcare experts, family, and emergency technician) and location entities representing symbolic spaces (i.e., living room, kitchen, and bedroom).

The architecture of the proposed platform, shown in Figure 6, consists of three layers: physical space layer, context management layer, and service management layer.

The physical space layer presents a smart home environment that provides context data from its attached entities such as sensors or computing devices. The context management layer gathers data captured from sensors in the first layer, filters sensor data in order to maintain useful data, then translate these data into context which can explain which situation happens around the user. On top of this layer, context

Figure 6. The platform of smart home-based healthcare system
Source: Lee & Kwon, 2013.



definition processor is implemented for services to acquire considered context data or subscribe to event notifications. Context definition processor interacts with the ontology manager for referring what's mean of the currently captured context. The ontology manager refers to the knowledge base which is developed with the OWL-based model that describes context-based rules. Third, the service management layer includes a context-aware reasoning module and an application interface. Context-aware reasoning module is based on the OWL-based model which describes context-based rules that can be used for constructing prioritized service lists. Also, this module provides a way for describing context-triggered actions, e.g., notifications or controlling home appliances. Services are triggered through the application interface with the situation aware-based reasoning results.

Personalized U-Healthcare Service System

In the work (J. Kim & Chung, 2014), authors proposed a U-healthcare service system and an ontology-based healthcare context information model to implement

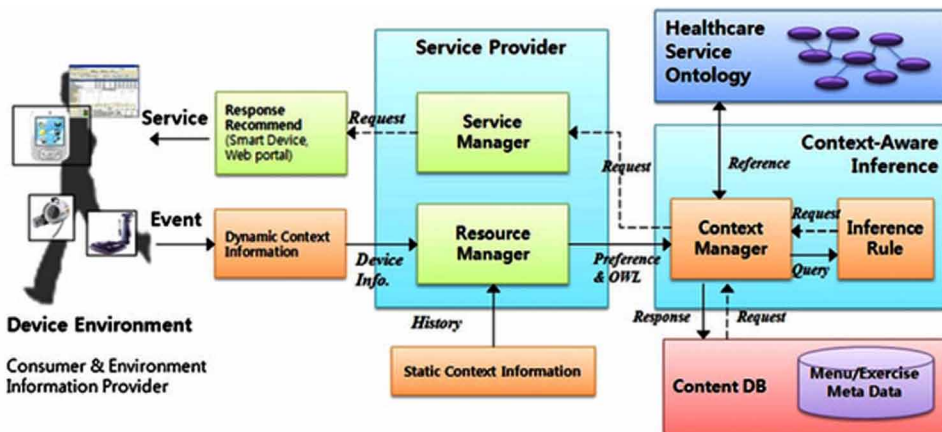
Background on Context-Aware Computing Systems

a ubiquitous environment. In this system, contextual information will be extracted and classified to implement the healthcare services using the context information model. The healthcare context information model can be defined using the ontology, and a common healthcare model will be developed by considering medical references and service environments. Application and healthcare service developers can use the sensed information in various environments by authoring device- and space-specific ontologies based on this common ontology.

The architecture of the U-healthcare service system is shown in Figure 7. The device environment related to human bodies is related to the parts that sense dynamic information according to the context of users and collects dynamic context information from devices. Service Provider is transmitted to the context-aware inference, which infers such context information, by transforming the collected context information. The Context Manager determines an item set through the inference rule after referencing a healthcare service ontology model with respect to the transmitted context information. After determining the item set, it is possible to obtain an item list presented in the content database. The obtained item list will be transformed to an environment that provides services through transmitting the obtained list to the Service Manager. Context-aware inference is a module that makes an inference based on the information received from Service Provider. Also, it determines an item set and recommends healthcare. Then, final services are provided to users through smart-phones, web portals, IPTVs, etc.

Figure 7. Architecture of U-healthcare service system

Source: J. Kim & Chung, 2014.



DISCUSSIONS

In recent years, pervasive systems have become a very active area of research so that we are surrounded by a swarm of embedded and smart devices; including sensors, smart phones, tablets, cameras, etc., interacting and exchanging information using wireless communication technology. U-healthcare systems are one of the main application areas of pervasive computing that provide us several services, such as monitoring health and wellbeing of patients anytime and anywhere using smart mobile devices. With the progress of ubiquitous technologies, more smart services can be provided in a smart home environment allowing patients to live safely and independently in their homes. For providing such services, this system has to react rapidly by analyzing dynamically not only the health measurements of patient, but also by analyzing his current location, his profile, his activities, and his physical environment. In fact, with the invasion of mobile devices in our life, pervasive healthcare systems can provide us mobile services or applications that allow monitoring the health and wellbeing of patients anytime and anywhere. However, the obstacles related to the limited resources of mobile devices, such as battery lifetime, hinder the service continuity in this kind of systems. Therefore, device resources have to be taken into account during the execution of these systems, and the service continuity on mobile devices must be assured. In order to deal with the different resources presented in the environments, this kind of system must adapt their behaviours according to the context change (Baldauf et al., 2007). They must be able to detect context information that comes from different and heterogeneous entities, infer new situations from this context, and provide the appropriate services to the user at the right time, in the right place and with the right manner.

Several researchers have been concerned about pervasive context-aware systems and context-awareness. Moreover, reports or white paper of many projects have been published increasingly. Various works in this field including context models, principal existing Context-aware development frameworks, and the most interesting works in pervasive healthcare systems are described in previous sections.

Context Models

Many researchers work in the area of pervasive and context-aware computing have developed different kinds of context models and each model brings along some reasoning techniques. In (Strang & Linnhoff-Popien, 2004) a comparison between Key-value models, Mark-up scheme models, Graphical models, Object oriented models, Logic-based models, and Ontology-based models, is presented. Authors concluded that Ontology-based models seem to be the most suitable tool for context modelling due to their high and formal expressiveness that can be used to describe

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complex context data. They also provide a good sharing of information with common semantics and they support reasoning tasks in a better way than the other modelling approaches. In addition, they can import the other existing ontologies for reuse of knowledge. However, according to (Nalepa & Bobek, 2014) Rule-based Reasoning allows for more complex reasoning than just a simple classification tasks provided by ontological approaches. Nevertheless, they cannot handle the highly changeable, ambiguous and imperfect context information (Bikakis et al., 2007). Spatial context models are well suitable for context-aware applications that are mainly focused on location-based scenarios. However, interoperability among different spatial models can be easily achieved when the location information is confined to very simple spatial data. For more complex spatial domains, interoperability can be obtained only by adopting expressive languages (e.g., coupling with a shared ontology of location) (Bettini et al., 2010).

It is obvious that until now, it is still a challenge to build a context model based on the complex heterogeneous information, ensuring that context is easily expressed, reasoned and shared. As there is no clear winner, the community nowadays considers hybrid models that combine different modelling techniques for different purposes to be the most beneficial such as the hybridization of ontology-based models with the rule-based reasoning in order to get most of their benefits.

Besides, a well-designed context model should provide an appreciable interpretation of all kinds of context, easily shared with the required component and conveniently handled by designers. It is required to model different scenarios and to allow developers/designers to easily add new context to this model, or even to provide the ability to import and reuse some existing context from another context model. The context model should be simple, expressible, general, and flexible; since at design time, we do not know what information will be relevant to all systems or applications. New applications may require new types of contextual information.

Frameworks for Context-Aware Applications

As described in a previous section, various frameworks to support context-aware development have been developed in literature, the most known works cited in this chapter are: Context Toolkit, CoBrA and SOCAM. The authors analyze the aforementioned frameworks based on the following facets: the architecture of the context-aware system, types of context, context modelling and context reasoning. Also, if the works support a generic context model and dynamic adaptation of applications. Table 1 summarizes the different works according to these facts.

The Context Toolkit is based on Widgets architecture and represents context by a set of key-value pairs. However, it is weak in supporting knowledge sharing and context reasoning. Key-value models are not convenient for complicated structure

Table 1. Summary of related works

	Design Approach	Type of Context	Context Modelling	Reasoning Support	Generic Context Model	Adaptation of Application
Context Toolkit (2000)	Widget	• User • Location	Key-value pairs	Does not provide reasoning capabilities	-	-
CoBrA (2003)	Agent	• User • Location • Environment	OWL Ontology	Rules and inference engine	-	-
CASS (2004)	Object	• User • Location	Relational data model	Rules and inference engine	-	-
CAMPU (2007)	Modules	• User • Bio-sensor data • Environment	OWL Ontology	Rules and inference engine	-	-
(Catarinucci et al., 2012)	Agent	• User • Bio-sensor data	OWL Ontology	Rules and inference engine	-	-
(Lee & Kwon, 2013)	Layered architecture	• User • Bio-sensor data • Location	OWL Ontology	Rules and inference engine	-	-
(J. Kim & Chung, 2014)	Modules	• User • Bio-sensor data • Location • Environment	OWL Ontology	Rules and inference engine	-	-

and do not allow a good reasoning on context. CoBrA is an agent-based system where context is modelled using OWL ontology which is integrated with a rule-based inference engine. However, this architecture has been developed to support applications that focus on spatial information. SOCAM is similar to CoBrA, since it also aims to build a middleware for context-aware services and uses OWL to model its context, but SOCAM goes further than CoBrA. The Ontology-based context model proposed in SOCAM defines an hierarchical approach for designing context ontologies. It provides ontology for general concepts in pervasive environments and domain-specific ontologies applied to different sub-domains. However, SOCAM uses the first order logic rules to determine high-level context, and is inadequate for dealing with complex context recognition in ubiquitous computing.

All these works proposed interesting architectures to support the development of context-aware application. Nonetheless, they do not support dynamic adaptation of applications to the mobile device constraint. In addition, almost all of those works

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do not provide a generic context model that can be used in other types of systems. They did not take into account the contextual information that can be gathered from bio-sensors; namely vital signs such as blood sugar and blood pressure measurements. Therefore, they cannot be used in healthcare field. In addition, those works do not hold the services selection and then, they do not allow providing the appropriate service to the user.

Ubiquitous Healthcare Systems

As described in the previous section, several interesting works are proposed in the field of pervasive healthcare system. The majority of these works have demonstrated the amenability of Ontologies and Rules for building context-aware pervasive computing systems. They have proposed interesting ontologies that can be used in the ubiquitous healthcare field. However, these ontologies are more specific to the healthcare context-aware system. Authors have modelled context according to their point of view and they did not provide a generic context model that can be used for building another context-aware system. In addition, they did not take into consideration the obstacles related to the limited resources of mobile devices, such as battery life time. Furthermore, they did not propose solutions to ensure the service continuity on mobile devices.

After studying the state of the art on context models, context-aware systems, and U-healthcare systems, authors conclude that till now, there is no generic context model and design approach that facilitates the context modelling, the design and the development of context-aware pervasive systems in general and pervasive healthcare in particular. In previous works, each researcher has used its own way to model and reason upon the context and has not proposed useful models that facilitate the design and the development tasks of this kind of systems.

Consequently, designing context-aware pervasive systems in general and U-Healthcare in particular can be laborious mainly due to the challenges faced in both research and practice. The major challenges that researchers and developers need to consider in this field include: how to represent the context, how to reason upon the context, how to provide the appropriate services to the end-user and how to ensure the service continuity on mobile devices? The difficulty to solve these challenges consists mainly in providing a useful support that facilitates the design and the development of those systems. Moreover, the complexity of pervasive systems is steadily increasing since there is a growing variety of mobile computing devices, which are highly connective and can be used for different tasks in dynamically changing environments. Due to this complexity, innovative ideas for the design and the development of these systems must be found.

CONCLUSION

Nowadays, the development of computing technologies has simplified the daily life tasks since the environment is improved by different applications. Pervasive computing is one of the most efficient computing areas which offer several smart systems aiming to provide various significant services in many areas of life such as healthcare, sport and education.

U-healthcare is one of the main application areas for pervasive computing which aim to provide several services that allow monitoring health and wellbeing of patients anytime and anywhere. This kind of mobile systems needs to adapt their behaviours according to the context change in order to deal with the different resources presented in the environments. Context-awareness is a central aspect of pervasive computing systems, characterizing their ability to adapt and perform tasks based on context.

This chapter was consecrated to provide background information about context-aware pervasive computing systems and ubiquitous healthcare systems. The most important aspects related to this kind of systems have been described. The major challenges that researchers need to consider when conducting research in context-aware pervasive computing systems have been reviewed. The well-known works in context-aware systems and Ubiquitous healthcare systems were discussed too.

Future work will focus on the proposition of a new design approach that facilitates the design and development of context-aware pervasive computing systems, especially pervasive healthcare systems.

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ENDNOTE

¹ The Free On-line Dictionary of Computing - <http://dictionary.reference.com>.

Chapter 2

The Internet of Things and Assistive Technologies for People with Disabilities: Applications, Trends, and Issues

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ABSTRACT

With the Americans with Disabilities Act (ADA), the past two decades have seen a proliferation of Assistive Technology (AT) and its enabling impact on the lives of people with disabilities in the areas of accessing information, communication, and daily living activities. Due to recent emergence of the Internet of Things (IoT), the fields of rehabilitation, healthcare, and education are challenged to incorporate the IoT applications into current AT services. While IoT applications continue to be developed and integrated into AT, they are still at a primitive stage where clear guidelines are yet to be developed and benefits are yet to be substantiated to ensure the quality of lives of people with disabilities. This chapter provides an overview of the IoT and AT integrated applications based on the building blocks of the IoT, along with recent trends and issues relevant to accessing technology for people with disabilities.

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INTRODUCTION

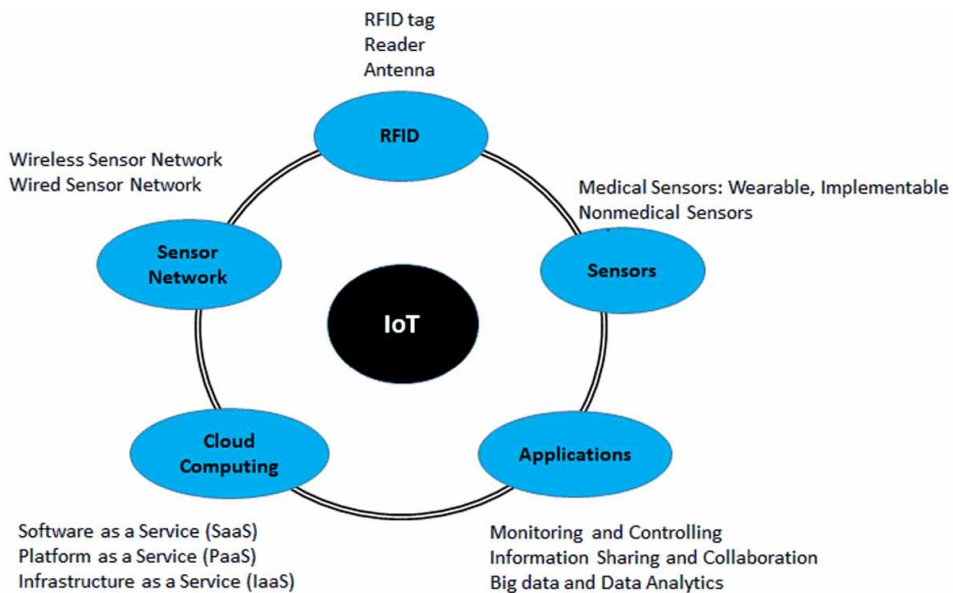
The IoT is reshaping our society by changing many aspects of everyday life of potential users (Bandyopadhyay & Sen, 2011). Smart health, assisted living, smart homes, and enhanced learning are only a few examples of possible application scenarios in which this new technology will play a leading role in the near future for people with disabilities (Atzori, Iera, & Morabito, 2010). The IoT for people with disabilities is likely to become more personalized to meet individual needs and user requirements. With large IT companies such as Intel, Cisco, Samsung, Google, and Apple developing the IoT ecosystems, newer and revolutionized IoT innovations for people with disabilities are emerging. The IoT allows medical devices and assistive devices to collect, store, send and receive patient and customer data and is likely to become an important part of their lives. While the IoT is one of the hot technologies of this decade and a large number of studies focus on the technical aspects of the IoT such as management of resource constraint devices and mechanisms of interconnection mechanisms (Bui, Castellani, Casari, & Zorzi, 2012; Gluhak et al., 2011; Atzori et al., 2010; Sehgal, Perelman, Kuryla, & Schonwalder, 2012), a paucity of studies exists on the use of the IoT for people with disabilities.

There is little doubt that the IoT is highly likely to enhance the use of Assistive Technology (AT) by increasing the accessibility and functional capabilities for people with disabilities in the areas of communication, self-care, independent living, health care, mobility and transportation, and education and learning (Lee, 2009). While the IoT is at the early stage of making a positive impact on the lives of people with various disabilities, the potentials for the range of benefits are unlimited. According to Gartner (2013), people with disabilities make up 15% of the world's population. Assistive technology devices marketed to people with disabilities can also be sold to the other 85% of the population that is "situationally disabled" during some part of their day. With the growing population of elders, more attention needs to be given to the elderly citizens who require accommodations in the areas of cognitive, physical, and sensory abilities that are associated with aging (Morris, Mueller, & Jones, 2010). Hence, healthcare and related area professionals need to have a better understanding of how people with disabilities may interact with various IoT innovations to help researchers and AT developers to develop more user-friendly and effective IoT-based AT applications. In the following, basic building blocks of the IoT architecture are explored for AT integration.

BASIC BUILDING BLOCKS OF THE IoT ARCHITECTURE

A suitable architecture for the Internet of Things (IoT) requires the implementation of several and distinct technologies in computing, communications, and data mining (Lopes, Pinto, Furtado, & Silva, 2014). As architecture will have a significant bearing on the field itself and needs to be investigated (Gubbi, Buyya, Marusic, & Palaniswami, 2013), basic IoT architecture needs to be established and updated continuously to commission and decommission various IoT assets. Domingo (2012) suggests three layers of IoT architecture: perception, network, and application. This layer architecture represents a hierarchical structure of IoT systems. To complement this hierarchical view of the IoT systems, five technology building blocks of the IoT architecture can be examined: Radio Frequency Identification (RFID), sensors, sensor network, cloud computing, and applications. Recent IoT devices for people with disabilities represent at least three, if not all, of these building blocks. Figure 1 shows the five technology building blocks with various technological components. These building blocks become the basis for AT that support independence, freedom, and dignity of people with disabilities in various environments.

Figure 1. The five technology building blocks



Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) refers to the system of electronic and computing devices which enables objects with an RFID tag embedded to be wirelessly identified and tracked. RFID use electromagnetic energy to wirelessly transmit data from the RFID tag to the RFID reader (Want, 2006). When the object embedded with the RFID tag passes near a reader, the electromagnetic energy emanated from the reader's antennas creates electric power for the tag to transmit stored data by radio wave to the reader. Major applications of RFID have been developed in the manufacturing, healthcare, and transportation sectors. RFID has become an important building block for the IoT (Lee & Lee, 2015). RFID tags can provide much of the essential data that the IoT devices need to provide. When used in hospital or homecare settings for people with disabilities, RFID-enabled AT applications allow care givers to identify the exact location of the people inside the premises of care services and monitor their movements in real-time. El-Basioni, El-Kader, and Elissa (2014) proposed a smart home that presents a complete solution for a supportive environment that utilizes the RFID system with AT applications for elderly citizens with disabilities. Also, a smart home with an RFID system allows people with disabilities to make meaningful contributions by completing tasks without which would not be possible (Neßelrath, Hauptert, Frey, & Brandherm, 2011; Mulfari, Celesti, Fazio, Villari, & Puliafito, 2014).

Sensors

One of the biggest drivers of the IoT revolution is the increasing number of low-cost sensors available for many different kinds of functionality (Swan, 2012). The sensor industry is accelerating technological innovations due to the market potential created by the advent of the IoT. Sensors can be either wired or wireless, and are used to monitor and alert change in environments such as temperature, weight, altitude, chemicals, moisture, light, sound, motion, etc. Sensors are often embedded in machines and devices. Smart sensor-based technology has enabled home automation utilizing various devices including lighting and temperature control, home security management devices, and adaptive kitchens (Domingo, 2012). The application of sensors can be divided into two major categories: medical applications and non-medical applications (Ameen, Liu, & Kwak, 2012). The medical applications of sensors can be of two types: wearable and implanted. Wearable devices are those that can be used on the body surface of a human or just at close proximity of the user to measure temperature and monitor blood pressure, respiration, heart rate, etc. The implantable medical devices are those that are inserted inside human body to monitor cardiac arrhythmia, brain liquid pressure, etc. (Ameen et al., 2012). The

sensor communicates with the other sensors to transmit collected data. A network of multiple sensors may be used to perform collaborative tasks. For example, a temperature sensor may work with a moisture sensor to keep the optimal level of the room condition for patients. Data generated by the sensor are used for data analysis and decision making. In another example, gathering patient medical data remotely helps provide emergency care, conduct diagnostics, and even administer preventive medical treatment. Accurate, automated, and real-time information reduce errors and improve quality and efficiency of medical services. Due to the miniaturization of IoT devices, sensors have the requirements of small size and energy efficiency. Various types of sensor devices are being utilized in smart environments for data gathering and management for people with disabilities (El-Basioni, et al., 2014; Joseph et al., 2015; Lambrinos & Dosis, 2013; Oniga & Sütö, 2014). Also, Busch et al. (2013) proposed a user-centered smart medicine cabinet with clear and self-explanatory interface elements along with AT features such as text-to-speech output. A noteworthy feature of this technology is the enhanced privacy, security, and trust of people with cognitive and motor disabilities.

Sensor Network

A sensor network connects sensors with one another, and transmits signals. While wired sensor networks are used for some IoT applications, they reduce the location independence of the sensors or sensor-embedded devices. A wireless sensor network (WSN) consists of a large number of tiny low-cost energy-efficient nodes that have small capacities of sensing, processing and communicating via radio medium (Demigha, Hidouci, & Ahmed, 2012). WSNs can be categorized into event-driven, time-driven, and query-driven (Barrenetxea, et al., 2008). While RFID is used for low-cost identification and tracking, WSNs bring IoT applications richer capabilities for both sensing and actuation (Lazarescu, 2013).

WSNs are gaining momentum in the IoT industry with the growth of IoT devices. Smart home, smart manufacturing, and smart city mostly depend on the WSN for the deployment of sensors and devices. Research in healthcare applications of sensor devices is currently under progress. Sensor networks applications in healthcare have potential for huge impacts. A wireless body sensor network (WBSN) with locally computational intelligence provides pervasive monitoring environment while at the same time guaranteeing the mobility of monitored patients (Aziz et al., 2008). These benefits can be realized through real-time, continuous vital monitoring to give immediate alerts to caregivers about patient status. As thousands of devices and sensors are connected, sensor networks need to be energy efficient, highly reliable, and secure.

Networking technologies in data collection allow users to control and monitor events in various settings. Sula, Spaho, Barolli, and Miho (2014) present an IoT based framework that utilizes a combination of robots, tablets, smart phones, laptops, and Playstation devices to help children with autism spectrum disorder accomplish various tasks. The integrated SmartBox device in this framework includes various sensors such as body sensor, chair or bed vibrator control, smell, sound, and remote control socket. This device is combined with various visual systems, such as objects, photographs, pictures, realistic drawings, line drawings, and written words for children who can readily comprehend the visual representation. Children with autism are highly interested and motivated by computers and touch screen tablets. Therefore, the integrated SmartBox device allows children with autism to interact, make choices, respond, gain new communication skills and create peer-to-peer (P2P) communication between children, caregivers and therapists. This assistive environment along with the use of heuristic diagnostic teaching process is expected to identify learning abilities and creative traits of students with autism (Sula et al., 2014).

An attempt to bring the IoT and AT together with the use of neural networks yielded a system that can contribute to the independence of people with disabilities (Oniga & Sütö, 2014). They propose a human activity and health monitoring system composed of micro-controller development board, a 3 axes accelerometer sensor, a heart rate belt sensor and communication modules, all of which is part of a smart environment with IoT and AT features. This proposed system is reported to have obtained positive recognition rates but researchers indicate that tests across settings and personnel are required for further utilization.

Cloud Computing

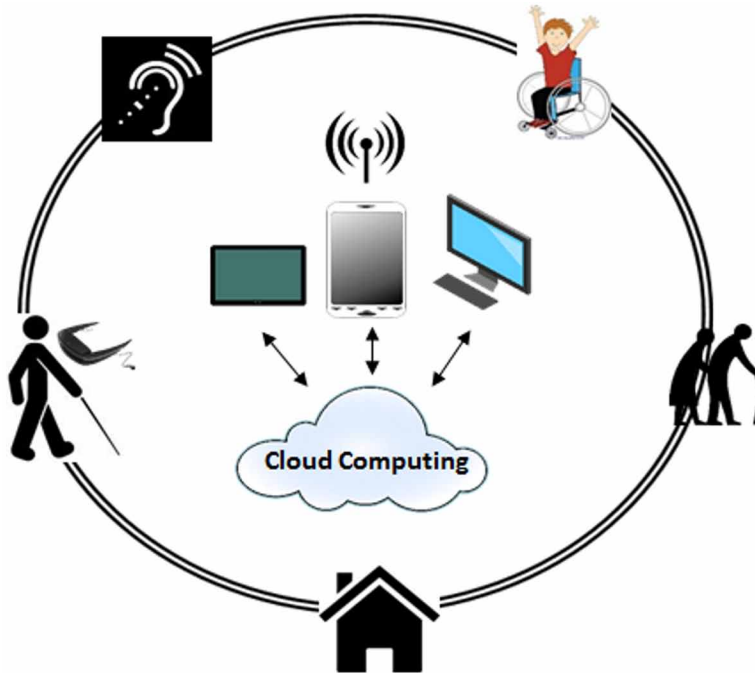
Cloud computing is a computing paradigm that relies on sharing computing resources such as servers, storage, bandwidth, and applications for an organization's computing needs. According to National Institute of Standards & Technology (Mell & Grance, 2011), "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." Cloud computing has five essential characteristics: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service (Mell & Grance, 2011). The three main services are provided by the cloud computing architecture to meet the various needs of users: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) (Buyya, Yeo, Venugopal, Broberg, & Brandic, 2009; Cusumano, 2010). The IoT devices generate enormous amount of data, which have to be stored, processed and shared (Gubbi et al., 2013). Main

deployment models include the public cloud, private cloud, community cloud, and hybrid. The community cloud is shared by multiple organizations with similar purposes of cloud deployment. The hybrid cloud is a cloud environment in which an organization owns and manages their private cloud and leverages a public cloud or a community cloud provided externally. Cloud computing has been recognized as a building block of the IoT architecture, since it can support gigantic data storage and processing needs of the individual sensors and devices. For example, the IoT devices can feed data to cloud datacenters for analysis and share data through the datacenter with other devices connected on the sensor network. Cloud datacenters possess the ability to increase and decrease computing capacity according to demand, while remaining accessible anywhere from any device. High performance data processing algorithms, control methods, and learning techniques can be installed and run at the centralized datacenters. The integration of cloud into IoT systems will accelerate the development of new IoT-based applications. With so much data generated by potentially billions of different sensors and devices, cloud computing will play the central role in filtering, analyzing, storing, and accessing data and applications in useful ways. Cloud computing can be one of the major potential enablers of the next generation smart environments for people with disabilities (Gubbi et al., 2013). Cloud-based IoT is considered a future trend (Dores, Reis, & Lopes, 2014). Cloud computing can decouple the AT devices from the computers by avoiding application installations on each available computer (Mulfari et al., 2015). IoT-based AT devices can make use of cloud computing to upgrade/expand functions without much of the user effort and time. Because cloud computing has such advantages as platform-independence, high reliability, high efficiency and scalability, the construction of cloud centers at hospitals and medical facilities can promote resource sharing and facilitate the development of highly reliable medical monitoring and management systems (Liu et al, 2015). Figure 2 shows a platform independent cloud-based IoT environment for AT devices for people with variety of disabilities.

Applications

The IoT can be classified into three major areas of applications: monitoring and controlling, information sharing and collaboration, and big data and data analytics (Lee & Lee, 2015). IoT applications are the most visible part to the users in the IoT system. IoT applications perform specific functions such as monitoring machines remotely, informing a caregiver of the real-time medical condition of a person with disability, and analyzing environmental data collected from sensors. Smart healthcare which monitors patients' living conditions and health status using small sensing devices and collecting their data over a network under daily life is expected as a new trend (Suzuki, Tanaka, Minami, Yamada, & Miyata, 2013). For example,

Figure 2. A platform independent cloud-based IoT environment for ATs



IoT-based applications for fall detection will provide help and security for elderly or disabled people living independently. IoT applications for collaboration will require constant communications and interactions between devices and devices, and devices and humans.

Monitoring and control can be part of a much larger collaboration application. For example, Nest has more than a dozen other IoT devices from various external developers that will collaborate with its thermostat in home automation applications. While monitoring and control devices may work independently of each other, collaboration applications require multiple devices working in sync for common purposes. For example, various sensing devices in building and facilities can perform collaboration for a smart building operation (Yu, Kim, Bang, Bae, & Kim, 2015). Big data and data analytics is another promising area of IoT applications (Lee & Lee, 2015). IoT data can be very large when data is generated over a certain amount of time (Liu, Yang, Zhang, and Chen, 2015). These IoT data can also be put to cloud datacenters for processing (Ma et al., 2012). The capacity of cloud datacenters is growing exponentially and storage capacity is now less of a concern, and the proper use of it to add significant value to the users and organizations is a more concern. For example, analysis of the huge data stored at the datacenter

may indicate certain patterns of when a person with disability is at health risk and may be able to alert health professionals of the impending problem. Busch et al. (2013) propose a user centered smart medicine cabinet that focuses on information sharing and collaboration. This technology provides a clear and self-explanatory interface elements along with AT features such as text-to-speech output function for communicating the system's trustworthiness state. A noteworthy feature of this technology is the enhanced privacy, security, and trust of people with cognitive and motor disabilities. While the above discussions are general and applicable for wide areas of the communities, the following section focuses on the AT applications in the context of people with disabilities.

THE IoT-INTEGRATED STATE-OF-THE-ART ASSISTIVE TECHNOLOGY

Assistive Technology (AT) has been developed to increase the quality of life of people with disabilities with improved services in education, rehabilitation, and healthcare (Alper & Raharinirina, 2006; Lee & Templeton, 2008; Scherer & Cushman, 2001). As the available features and options of AT have increased, their use has been more widely considered and recommended (Scherer & Cushman, 2001). According to the U.S. "Technology-Related Assistance of Individuals with Disabilities Act of 1988" (P.L. 100-407), Assistive Technology is defined as "any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities." Types of AT include communication tools including text-voice converter, education aides for reading and writing, daily living devices such as robotics for household maintenance, mobility, and home automation such as smoke detectors, remote lighting, and water control. Since the advent of the IoT, some of the traditional ATs have been gradually integrated into IoT capabilities. Types of disabilities that are currently supported with IoT-integrated ATs include hearing, vision, mobility, cognition, and learning disabilities. This section explores what IoT-integrated ATs have been developed and are under development to empower the people with disabilities. In the following, we discuss IoT-integrated ATs for people with hearing impairment, visual impairments, and mobility disabilities.

IoT Applications for People Who Are Deaf or Hearing Impaired

The IoT is improving the lives of the hearing impaired and deaf. People who are hearing impaired can benefit from external or internal (implanted in the ear) AT devices and sensors that helps improve hearing. The three major design features of

AT devices for the hearing impaired are: sound amplification, visual information output (e.g., flashing lights, sign language, and text output) and tactile output (e.g., vibrating alarm clock). In an IoT-based home automation setting, sensors monitor the surrounding environment and detect certain events such as heat, smoke or fire that triggers an alarm signal which in turn is sent to the control station. The control station forwards it to the AT device as an amplified alarm signal for the hearing impaired or flash signal for the deaf.

HandTalk is a low-cost, portable gesture-to-speech glove prototype designed to help the hearing impaired communicate with those who are not familiar with the American Sign Language (ASL) (Sarji, 2008). HandTalk has a simple mechanism to switch from standby to ready mode and back, and uses commercial-off-the-shelf applications compatible with standard cell phones and hand held devices. The glove is fitted with flex sensors which sense the position of the fingers and sends it to a monitoring station using Bluetooth. If the position data matches the set of values associated with an ASL sign of a stored database, the sign is converted into text and finally into speech.

The hearing aid market is one of the largest markets for the hearing impaired. A number of tech companies are competing to grab the hearing aid market with IoT integration. In the 2015 International Consumer Electronic Show, Siemens has introduced the EasyTek smart hearing aid system which adds functions and connectivity of each hearing-aid via Bluetooth to an EasyTek disc that people wear around their neck. The EasyTek disc is used to control the volume in the device, or turn the hearing aid on or off. The device also connects via Bluetooth to the Siemens EasyTek app on iOS or Android devices to control the parameters of the hearing aid (iTunes, 2016). The device has noise cancellation technology that removes noise and amplifies the voice of the person who is directly in front of the hearing aid wearer. This system exemplifies the idea of the IoT-integrated monitoring and control. Smart Hearing Aid, a Bluetooth ear set with a hearing aid feature is another example of using smartphones for hearing aids. While wirelessly connected to users' smartphones, Smart Hearing Aid provides basic ear set features such as hands-free voice calling and CD-quality music play and offers a four-channel hearing aid feature for people with hearing loss via a smartphone app (SK Telecom, 2015). Building on the existing Bluetooth standard that is widely supported in today's smartphones, tablets and personal computers, the IoT will give hearing-impaired users the same choice of products and opportunities as everyone else.

The individual hearing aid system collects data about device setting, age, gender, audio preferences and their everyday listening environments. These data can be uploaded to the cloud datacenter for further analysis. Big data analytics of hearing aids is another example of a paradigm shift in the hearing science. The IoT enables the recording of personalized hearing adjustment and linking the data for

further remote analysis at the datacenters. In the near future, hearing aid users will get the opportunity to participate in hearing aid development. Results by hundreds of thousands of users will be submitted to big data analysis engines, aimed at algorithm optimization for audiologists (de Vries, 2014). The IoT-integrated hearing aids fully realize the application of monitoring and control, information sharing and collaboration, and big data and data analytics. One of the more recent medical technologies, cochlear implant (CI) (American Academy of Audiology, n.d.), has been widely implemented for infants as young as 3 months old. The effectiveness of CI has been well-received but not without resistance from the deaf community. Considering the critical language acquisition period hypothesis, CI is considered most effective when done as early as possible for the acquisition of speech sounds. Whether CI is the miracle ear as some consider it is yet to be witnessed with further efficacy studies. The good news for the deaf is that recent CI technology has shifted from auditory based only system to an IoT-integrated system with additional text and image based output.

Another application of the IoT-integrated ATs for the hearing impaired and a deaf is in the area of home networking. LIFX pioneered a smart light with the wifi-enabled, multi-colored LED that is controllable via a smart device (LIFX, n.d.). LIFX light bulbs flash red to let hearing impaired users know there might be danger from elevated smoke or carbon monoxide (CO) levels. The environment also has a multitude of Internet-connected displays, RFID, and other near field communication (NFC) scanners. The deaf person brings a tag which is continuously monitored by a scanner. As his identity and location and subsequent preferences are known to the LIFX systems, the connected displays in the person's vicinity can adapt their signage to the appropriate modality.

IoT Applications for People Who Are Blind or Visually Impaired

The three main common design features of AT applications for people who are blind or visually impaired are: magnification (e.g., zoom text, large fonts), auditory output (e.g., screen reader, text to speech output devices), and tactile information output (e.g., braille, raised maps). Individuals who are blind have been less dependent upon other individuals due to AT applications that enable them to complete tasks in daily living skills. These include color and pattern analyzer for dressing and speech output applications for accessing information on the web, books, and emails. As a navigation tool for people who are blind, the white cane, a tactile based device, has been used for several decades. Multiple IoT-integration projects will give more options for people who are blind, and the white cane may become a thing of the past. The Indoor Navigation Project at Curtin University will enable people who are blind to sense their surroundings using special multi-sensor array technology

(Curtin University, 2013). The special multi-sensor array technology senses an entire room's features, builds a virtual map of it and communicates this to the user. Unlike a cane with limited range of sensing, the multi-sensor device covers a wide range and types of sensing and mapping including the change of velocity, images, or noise in an indoor environment.

A 3-D navigation system for the blind was developed at the Institute of Intelligent Systems and Robotics at the Pierre and Marie Curie University in Paris, France (Jablonski, 2012). It consists of a pair of glasses equipped with cameras and sensors utilizing sensing systems for robots, and a handheld electronic Braille device. The system produces a 3-D map of the wearer's environment and his/her position within it that is constantly updated and displayed in a simplified form on the handheld device and helps blind people to move about indoor and outdoor spaces independently. It uses a collection of accelerometers and gyroscopes that keeps track of the user's location and speed. This information is combined with the image to determine the user's position in relation to other objects, which are transmitted to the handheld Braille device to be displayed as a dynamic tactile map. Recently, a navigation system using a wearable sensor and social sensors to increase situational awareness for the blind utilizing real-time localization technologies was created (Joseph et al., 2013). This navigation system promotes independent traveling for the blind by utilizing the information of the events gathered from the Internet.

Another IoT-based new navigation system for the blind is MIT's EyeRing, which uses a small camera worn as a ring which was developed by a team from the Fluid Interfaces Group at MIT's Media Lab. This device translates images of objects captured through a camera into aural feedback to aid the blind. The ring takes a picture or a video that is then sent wirelessly to a mobile phone, where an application analyzes the content and reads out an answer. It consists of a 3D-printed ABS nylon outer housing containing a small VGA camera unit, a 16 MHz AVR processor, a Bluetooth radio module and a 3.7V Li-ion battery (Ridden, 2012).

Many IoT applications utilize wearable technology such as smart watches, smart wristbands, and smart glasses. Many wearable devices are used to track how many steps the user takes, or even how many miles the wearer traveled, but has not been used for the visually impaired. A startup company called Ducere Technologies is looking to use wearable technology along with the IoT to make the lives of the visually impaired much easier. The company is developing a touch-based interactive footwear called Lechal (Lechal, n.d.). A specialized shoe insole vibrates to alert users when they're supposed to make a turn, acting like a real-time GPS device for their feet, directing the wearer where he or she should go (Annear, 2014).

Like Bluetooth-based hearing aid, Bluetooth technology is also integrated to help people who are blind or visually impaired. An Austrian company called Indoo.rs and the San Francisco Airport (SFO) department are developing iOS assistive technolo-

gies with iBeacons sensors to create an indoor navigation system for the visually impaired at SFO Terminal 2 (Param, 2014). This innovative app uses a couple of hundred iBeacons installed throughout the terminal not only to facilitate physical movement through space, but also to provide intelligent navigation to people who are blind or visually impaired by speaking out various objects and locations in the terminal. The users download the indoo.rs app on their iPhone. iBeacons, which are placed near an object, use Bluetooth to transmit a unique identifier of an object to the user's iPhone to look up information related to the ID over the Internet.

IoT Applications for Mobility Disability

AT for mobility/ambulation can also be referred to as ambulatory aids. Ambulatory aids clean floors and items, water plants, control light and temperature, open and close garages and perform other functions to ensure safety, comfort, and convenience for the people with mobility disability. The IoT brings ambulatory aids new capabilities. A smart connected wheelchair is a concept designed by Intel interns as part of the Intel Collaborators program, and has been endorsed by the award-winning theoretical physicist, Stephen Hawking (del Castillo, 2014). This wheelchair is capable of monitoring vitals of the person sitting in the chair, including blood pressure, heart rate, and body temperature. The wheelchair is also equipped with an application that allows wheelchair users to rate accessibility of different locations, further enhancing the user experience. It even informs the users of the wheelchair's status, keeping them even more safe and comfortable wherever they may go. The IoT systems for the people with mobility disabilities need to collect, analyze, and apply recommendations autonomously and unobtrusively. This connected smart wheelchair enables monitoring and control, information sharing and collaboration, and big data and data analytics. An application called 'use-case' enables children with cerebral palsy to interact with their toys and their caregivers through a mobile device such as smart phone or tablet which has an installed learning game (Lopes, Pinto, Furtado, & Silva, 2014).

Brain-Computer Interfaces (BCI) systems help people with severe motor disabilities to regain independence to some extent (Leeb et al., 2015). BCI systems use brain signals as a communication and control channel to perform navigation tasks through a bidirectional audio/video connections to a telepresence mobile robot. BCI users are able to have interactions with family members and friends at different locations from the users. While BCI technology significantly improves the quality of human to human interaction to some extent, authors caution that controlling the robots is a complicated task and that shared control can better facilitate the BCI operation than direct control. Lambrinos and Dosis (2013) propose a parking space management system for people with disabilities utilizing monitoring technology which integrates

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sensor and smart phones, and wireless and mobile communications. This system can assist the parking authorities with usage monitoring to allow better parking space allocation used for people with mobility disabilities.

Cognitive info-communications (CogInfoCom) is used to help people with mobile disability. CogInfoCom is based on the research of virtual reality systems to create special three dimensional (3D) environments in the hope that through which people with disabilities can actively participate in the labor market (Juhasz, Juhasz, Steiner, & Kertesz, 2013). The use of 3D environments such as office environments with IoT applications should be given to careful examination of individual differences such as preferences, interests, and cognitive abilities. Home automation and security applications also offer benefits to people with disabilities or older adults. Home automation applications allow people with mobility disability to change thermostat settings remotely, adjust lighting, activate security alarms and cameras, control appliances, and control door locks, typically via smartphones and online monitoring. Smart transportation and self-driving cars are also helpful new options for people with mobility disability (American Association of People with Disabilities, 2015). El-Basioni, El-Kader, & Eissa (2014) propose a smart home wireless sensor networks called E/D-WSH system suitable for elders and people with disabilities. E/D-WSH system offers a complete solution for the whole home environment with entering system, fall detection system, RFID system, lighting system, microphone/speech recognition system, proximity sensor/sound synthesizer system, gas leakage detection system, electrical devices monitoring and home structure health system. As shown in various applications, IoT consistently help improve the safety of the people with mobility disability by gathering information on user patterns, environmental dangers, assessing the individual's needs, and taking and proactive measures when a safety threshold has been breached. Table 1 summarizes various IoT studies reviewed.

TRENDS OF THE IOT TECHNOLOGIES FOR AT

A rapid advancement in the IoT technologies for AT has been made in network, software and algorithm, hardware, and data processing. Network technology is moving to unobtrusive wire-free communication technology and a context-aware autonomous network (Sundmaeker, Guillemin, Friess, & Woelfflé, 2010). While RFID tags and sensors have been the focus of hardware innovation, miniaturization of hardware and nanotechnology is leading the energy-efficient hardware evolution as shown in Smart Home technology for people with disabilities. Since processing a large amount of IoT data in real-time will increase workloads of data centers at

Table 1. IoT for people with disabilities: roles, application category, benefits, and future works

Authors	IoT Roles	IoT Application Category	Benefits	Future Work
Busch et al. (2013)	• A user-centered smart medicine cabinet that informs about potential privacy and security risks along with helping users manage their life • Clear and self-explanatory interface elements, readable font size, and clear visual design • Acoustic reminder for taking medicine, haptic feedback for communicating the system's trustworthiness state, using text-to-speech functionalities	Information sharing and collaboration	Enhanced privacy, security, and trust of people with mental and physical disabilities	• Expansion of the cabinet to people with dyslexia or impaired vision to see how well they can use the cabinet and how trustworthy it is perceived by them • Publish guidelines about how best to present security information to people regardless of their disabilities. That way everyone can have a trustworthy experience in the IoT
Dores, Reis, & Lopes (2014)	Machine to machine instant messaging platform useful in Integrating the cloud Internet platform and diverse IoT devices	Information sharing and collaboration	Care system for people with disabilities for more independence through cloud-based communication systems	Various security technologies need to be tested and improved for quality of service
El-Basioni, El-Kader, & Eissa (2014)	Elders/Disabilities Wireless Smart Home for assistive independent living (E/D-WSH)	Monitoring and control	• The home automation system which can be controlled locally using a remote control or an application on a PC or laptop, or remotely through the Internet • A complete solution for the whole home environment for elders and disabilities by designing entering • system, fall detection system, RFID system, lighting system, microphone/ speech recognition system, proximity sensor	• Realizing energy saving of smart home technology by using alternative power especially the solar power • Continuous measuring of power consumption of different devices to help home owners manage their use of electrical devices
Jablonski, C. (2012).	Sensing systems for robots to help for people with visual impairment navigate unknown terrains	Monitoring and Control application	The system produces a 3-D map of the wearer's environment and his/her position within it that is constantly updated and displayed in a simplified form on the handheld device	Need to be integrated with mobile phones and voice-assisted devices
Joseph et al. (2015)	• Assistive navigation using wearable sensors and social sensors for people with visual impairment • Fusion of social media messages, wearable sensors, and real-time localization technologies	• Monitoring and control • Information sharing and collaboration	Enhanced situation awareness with crowdsourced social media data	• Need to improve the quality using more rules and patterns • Further research on obstacle objects recognition, such as recognizing chairs or stairs
Juhasz, Juhasz, Steiner, & Kertesz (2013)	• Personal 3D environments for people with special needs or disabilities • The physical surroundings of the subject is combined with representations of virtual reality	Information sharing and collaboration	Provide people with disabilities to join in the workflow of a company	Need to do further testing in real life situations
Lambrinos & Dosis (2013)	Parking space management for people with disabilities	• Monitoring and control • Information sharing and collaboration	• Better utilization and management of parking spaces allocated for use by people with disabilities • Assisting the authorities with usage monitoring for law enforcement as well as capacity planning purposes	Various improvements to the system concentrating on user verifications and reservation enforcement which will enable for reservations to be made for future time periods

continued on following page

Table 1. Continued

Authors	IoT Roles	IoT Application Category	Benefits	Future Work
Leeb et al. (2015)	Brain-computer interfaces (BCI) systems with a telepresence robot for people with severe motor disabilities	Information sharing and collaboration	• Use brain signals as a communication and control channel to complete navigation tasks of a mobile robot • Empower people with severe motor disabilities to regain a degree of independence	More extensive comparisons with alternative systems
Lopes, Pinto, Furtado, & Silva (2014)	Two use cases that are currently being deployed for people with visual impairment and people with neurologic impairment	• Monitoring and control • Information sharing and collaboration • Big Data and data analytics	Improving the independence of people with visual impairment and people with neurologic impairment for	Currently laboratory stage. Need to test the use cases with users and analyze their adaptation to the AT devices
Mulfari, Celesti, Fazio, Villari, & Puliafito (2014)	The usage of embedded systems able to interface sensors and existing AT software tools running on user's personal computing devices	Information sharing and collaboration	Decouple AT software tools from the accessed computer systems, allowing us to control various kinds of computer systems, in order to natively interact with many platforms	Integration of plugins with cloud computing platform is needed in order to natively interact with many computers
Neßelrath et al. (2011)	A fusion of several systems comprising the intelligent medicament blister and the task-based calendar	• Monitoring and control • Information sharing and collaboration	The intelligent medicament blister helps to increase a patient's compliance and the task-based calendar assists people with cognitive disabilities in their activities of daily living like cooking tea	Seamless integration of multiple vendor systems based on open standards and architectures
Oniga & Suto (2014)	An assistive assembly consisting of a smart and assistive environment, a human activity and health monitoring system, an assistive and telepresence robot, together with the related components and cloud services	• Monitoring and control • Information sharing and collaboration • Big Data and data analytics	Adaptive capability and learning behavior of AT devices for independent daily life assistance of elderly or persons with disabilities	• Further testing of the systems in different circumstances and with different people • Need for further simulation of more artificial neural networks types for activity/health status recognition
Sarji (2008)	"Smart glove" that can recognize basic hand gestures and convert them into written words	Information Sharing and Collaboration	A low-cost, portable gesture-to-speech glove prototype	• Currently the device can convert only few words, suggests that sensor gloves can be used for partial sign language recognition • More sensors need to be employed to recognize full sign language
Sula, Spaho, Barolli, & Miho (2014)	An AT system combined consisting of the IoT, peer to peer technology and heuristic diagnostic teaching principles	• Monitoring and control • Information sharing and collaboration	• Use of the smart environment to support students that are diagnosed within Autism Spectrum disorder (ASD) • Better support the students during their learning by actively engaging the students during their learning and creating and maintaining their calm alert state	Need to evaluate the assessment results to design learning objectives and lessons for students with autism spectrum disorder

an exponential rate, data processing will become more context-aware, optimized and cognitive. The challenge is to identify issues associated with data storage and processing as IoT technology is increasingly applied to AT.

Smart Sensors

Spencer, Ruiz-Sandoval, & Kurata (2004) define smart sensors with four features:

1. On-board computing capability,
2. Small size,
3. Wireless communication, and
4. Low cost.

According to WinterGreen (Kharif, 2013), the current size of the smart sensor market is about 65 million devices, but it is expected to reach 2.8 trillion devices by 2019. Advances in sensor technology have enabled miniature smart sensors to unobtrusively monitor physiological signals, body posture, type and level of physical activity, and environmental conditions (Milosevic, Milenkovic, & Jovanov, 2013). Due to the explosion of the data collected with the proliferation of the IoT devices, sensors need to monitor the data quality and perform preliminary data processing. A smart sensor includes a microprocessor that can be used for digital signal processing, data filtering, self-diagnosis, self-identification, and self-adaptation. Some smart sensors can be programmed to send alerts to users when predefined events take place. IBM is developing Secure Living project utilizing smart sensors (IBM, n.d.). The homes for senior citizens and people with disabilities equipped with remote sensors to monitor the environment in real time, checking for changes in temperature or potential dangers such as water leaks or high levels of carbon monoxide. Data is transmitted and displayed on a dashboard in an off-site central control room, and on an assigned operator's Android mobile device via e-mail, SMS or Twitter. When problems arise and immediate action is required, alerts are sent to family members, volunteer 'angels,' members of the social services department or local emergency staff, based on the individual's specific need. The smart sensors can also learn the user's preferences and adjust its behaviors accordingly.

Self-Powered Sensors

Because of the large number, small sizes and complicated surrounding environments, powering wireless sensors with conventional batteries creates challenges in replacement or on-site charging of the batteries (Gheibi, Latifi, Merati, & Bagherzadeh, 2012; Huang et al., 2010). Since batteries have a limited life and need to be maintained regularly, the consumption of electric power by the batteries of the wireless sensors limited the scope of the IoT applications for AT devices (e.g., patient monitoring). Self-powering of electronic devices has emerged as a viable solution by integrating a power generator that can scavenge and turn the surrounding local

energy into electrical energy to drive the electronic devices sustainably without any other electrical input (Gheibi et al., 2014). Self-powering sensor technology offers advantages of location independence, minimum space, and zero wired-power requirements. Self-powering sensors use a variety of methods to generate or store electricity such as inductive switches, solar cells, and thermo-energy harvesters. Wireless Body Area Networks (WBANs) medical applications are actively utilizing smart and self-powered sensor devices that can be attached, or even implanted into, humans to monitor their physiological parameters (e.g., temperature, blood pressure, heart pulse rate, etc.), body motion as well as their surrounding environment. All the monitored parameters are then transmitted wirelessly, using short-range on-body or Intra-WBAN communications, from the on/in-body sensors to the monitoring centers for further data processing and analysis (Alam & Hamida, E2104).

Nanotechnology Sensors

Nanotechnology encompasses various technologies that cross sectors, such as nanomaterials (NMs), medicine, devices, fabrication, electronics, communications, and energy. There has been a phenomenal development in nanotechnology during the last two decades (Leary, 2010; Weiss, 2010). Nanotechnology will be driving a strong force in developing miniaturized sensors and related AT devices. Operating on the scale of atoms and molecules at the measure unit of 0.001 microns, nanotechnologies promise dramatic improvements in sensor designs and capabilities. Nano-size materials display different properties from bulk (or micrometric and larger) materials as a result of their size. These differences include physical strength, chemical reactivity, electrical conductance, magnetism, and optical effects (Rai & Ingle, 2012). Nanotechnology sensors are tiny, lower weight, and energy efficient. Nanosensors and nano-enabled smart sensors have applications in biosensors, diagnostics, environmental monitoring, drug delivery, therapeutic, healthcare, medicine, etc. Considerable efforts are made to reduce the cost of nano-size materials, improve reliability, and create useful sensors. Zhu et al. (2015) propose a clustered-sensor system through a project called SPHERE to provide analytics-driven, data gathering platforms for the field of healthcare management. This proposed system, currently being implemented in a real house, aims to bridge e-health and IoT by processing the sensor based data in real time for health monitoring.

Context-Aware Computing

Context-aware computing has the capacity to be aware of environments and their characteristics through sensors. In the IoT environment, a large number of devices are connected with each other and it is not feasible to process all the streaming data

available to those devices. Understanding the context makes it easier to perform machine-to-machine and machine-to-human communication as it is a core element in the IoT vision (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014). Context is classified into a low-level context involving time, location, identity, and activity, which are the most utilized contextual information, and a high-level context, which involves any other information that can be derived from the low-level types (Abowd et al., 1999). The success of context-aware information delivery requires an effective localization solution, as context-aware applications need to know the location of the user/object to determine and provide relevant information and services. Bradley and Dunlop (2008) discuss how contextual information such as location and personal preferences can be embedded into user-computer interactions and how these facilities and capabilities could be used to assist the visually impaired traveler on a long distance journey. Smart phones are a valuable platform that bears significant potential to support context-aware applications along with built in accessibility features (Li & Becerik-Gerber, 2012). Context-aware AT devices will possess a high level of intelligence in their control, actions and interactions with people with cognitive disabilities, offering them high level of comfort and functionality.

Interoperability of the IoT Systems

The IoT ecosystem needs to support interactions among many heterogeneous sources of data and many heterogeneous devices through the use of standard interfaces and data models to ensure mapping and cross-referencing among applications and services in order to exchange data. Interoperability is significantly more challenging for the IoT as it is not only about connecting people with people, but about a seamless interaction between devices and devices. Two types of interoperability are identified:

1. **Technological Interoperability:** The IoT devices can differ regarding their technological capabilities, and
2. **Semantic Interoperability:** For full interoperability, it is necessary that the devices interpret the shared information correctly and act accordingly (Gazis et al., 2015).

Standards play an important role to create collaborative technological solutions both within a single service provider and across multiple providers. Standards remove ambiguity about the interpretation of the information they exchange. Standards regarding communication, data sharing, and application interfaces will ensure that the IoT devices collaborate with each other. Standards for interoperability are a prerequisite for the integration of the multi-vendor AT devices for people with multiple disabilities who need comprehensive support services.

Other Trends

The principle of universal design, which promotes product development to reach the widest range of individuals with varying abilities, has been the basis for the development of various AT applications (www.cast.org). One such example is the built-in accessibility features in products such as computers, tablets, and mobile phones. These seamless features allow people with disabilities to access information, participate in social media, and IoT applications. These built-in accessibility features enable customization for people with disabilities at no extra cost. For example, keyboard functions can be manipulated to control the rate of typing and manner of pressing keys for people with limited motor abilities; sound input can be controlled via amplification and speech recognition; and screen display modes include visual notifications, magnifiers, and different text sizes (Apple, n.d.; Microsoft, n.d.). It is expected that the principle of universal design is widely applied to the design of IoT devices to allow people with disabilities to access services with high-levels of comfort and ease.

Another significant trend that has been getting increasing attention is the development of numerous smartphone-based applications for learning, mobility, communication, information sharing, and monitoring. For example, the iPad is utilized as a platform for applications in various areas of learning and communication (Catlett & Turan, 2013; More & Travers, 2013). Naturally, many pages of recent technology journals cover the studies that examined the effectiveness of iPad apps for reading, attention, communication, and cognitive support. Exhibits at technology conferences shift from small hardware devices to applications and software devices for learning, communication, and daily living. iPad-based applications are taking over other traditional AT devices, especially in the categories of education and communication.

ISSUES OF THE IOT-BASED ASSISTIVE TECHNOLOGY FOR PEOPLE WITH DISABILITIES

Barriers to accessing technology for people with disabilities have been addressed (Lee & Templeton, 2008). New issues arise when the IoT meets ATs. Based on the literature of AT practices, this section identifies several issues in the IoT-integrated AT development. There is an urgent need to address the issues in security, privacy, reliability, changing roles of health care professionals, and involvement of users and families to seamlessly integrate the IoT into the ATs.

Security

Security is defined as the subjective probability with which consumers believe that their personal information (private and monetary) will not be viewed, stored, and manipulated during transit and storage by inappropriate parties in a manner consistent with their confident expectations (Flavián, & Guinalú, 2006). Kalakota & Whinston (1996) define security threat as a circumstance, condition, or event with the potential to cause economic hardship to data or network resources in the form of destruction, disclosure, modification of data, denial of service, and/or fraud, waste, and abuse. Security threats also include data theft, resource theft, fire, natural disasters, burglaries, virus, and cyber-terrorism. Connected IoT devices are likely to fall victims in unsecure networks. A survey conducted by PricewaterhouseCoopers has indicated that the total number of security incidents has increased 48% over 2013. According to a Hewlett-Packard (HP) report (Kovacs, 2014), a total of 250 security holes have been found in tested IoT devices - on average, 25 per device. The issues are related to privacy, insufficient authorization, lack of transport encryption, inadequate software protection, and insecure web interfaces. With HP reporting that up to 70% of devices developed for the IoT are vulnerable to cyber-attacks, the need to 'lock down' mission critical' data across multiple applications has never been greater. Vulnerabilities of the IoT will continue to arise as more and more devices are connected to the IoT world.

Privacy

Privacy is defined as a two-dimensional construct with physical space and information (Goodwin, 1991). Any application that collects data from users has to be clear about what it collects and how it is used in order to build trust. Ackerman, Cranor, and Reagle (1999) gave participants four scenarios in which they had to indicate whether they were comfortable providing various types of personal information. A majority of users were very comfortable with providing general information (e.g., favorite food) and somewhat comfortable with providing directory-type information (name, address, e-mail), but they were uncomfortable with providing financial and health information (e.g., credit card, health status). For questions relating to the users' general attitudes regarding providing personal information, Ackerman et al. (1999) concluded that users can be classified as:

1. Marginally concerned,
2. Privacy fundamentalists (users who are very concerned with privacy), or
3. Pragmatic (users whose concerns vary as a function of the type of transaction being performed).

People with disabilities show various levels of privacy concerns when it comes to using ATs. With connected IoT devices deployed around users' homes and bodies and potentially collecting data that government and other third parties can access, they may start to self-consciously protect their privacy. Government regulation of the IoT privacy is under way. The Article 29 Working Party, a European Union privacy body (Justice, n.d.), and the Article 5(3) of Directive 2002/58/EC as amended by Directive 2009/136/EC (the ePrivacy Directive) stipulates that Member States shall ensure that "the storing of information, or the gaining of access to information already stored, in the terminal equipment of a subscriber or user" is only allowed on the condition that the subscriber or user concerned has given his or her consent, having been provided with clear and comprehensive information in accordance with Directive 95/46/EC6 (the Data Protection Directive), inter alia, about the purposes of the information processing. These documents say consumers should remain in control of their personal data throughout the life of the product. In some parts of Europe, such as the U.K, the industry is working closely with the government which is a desirable way of developing guidelines.

Reliability

In industrial environments or in emergencies, even temporary failure of AT devices is unacceptable. Hence, resilience and reliability issues in the AT devices need to be addressed from an overall system point of view and include such dimensions as availability, robustness, and flexibility of the devices to changing environmental conditions, and the robustness of data processing to uncertain information (Gazis et al., 2015). The IoT devices have to be resilient to communication errors by providing efficient mechanisms for information distribution especially in the multi-hop scenario (Maalel, Natalizio, Bouabdallah, Roux, & Kellil, 2013). System reliability is the result of a combination of individual reliabilities and the weakest component dominates the reliability of the entire system. The failures of the entire IoT system are experienced more frequently when there is a large number of deployed devices and sensors. Mathematical models of failure analysis may provide greater insight into the probability and costs of failures and requirements for minimum acceptable performance. There are multiple components in any IoT system. A well-designed system requires understanding of exactly what is a dominant reliability-related component in the IoT system and therefore needs redundancy and backups. For example, a single sensor may cause the entire system to stop functioning, and therefore redundancy of the sensor can be warranted.

Changing Roles of Health Care Professionals

Implementing AT services in rehabilitation programs is a complex process. AT selection and services are influenced by the availability of AT options, knowledge and experience of professionals, and budget limitations (Okolo & Deidrich, 2014). While the effectiveness of AT on learning and daily lives for people with disabilities across ages has been well documented, professionals face multiple challenges in providing effective AT services, especially in compliance with federal laws, funding, training, and collaboration. Due to the recent technological advancements in AT devices along with the IoT, healthcare professionals are faced with new challenges. The paradigm shift to the IoT-integrated AT will change the roles of various healthcare professionals. People with disabilities will be more empowered with more personalized and user-centered services. Many healthcare professionals may have doubts about their future position as the self-service component of the IoT-integrated ATs accelerates. To remain most valuable in the value chain of the AT industry, they need to retrain themselves for new value added services and new technologies and need to be willing to adapt to all possible changes in their area.

Involvement of Users and Families

AT services are typically provided by a number of multidisciplinary professionals including occupational therapists, physical therapists, speech therapists, teachers, and rehabilitation technologists. Families of people with disabilities should be included as meaningful partners in the implementation of AT applications. Yet, the key elements of the existing literature on the IoT-integrated AT do not necessarily include family as an integral member of the technology application process. Developing cultural sensitivity in the selection and use of AT devices and services is critical for people with disabilities and their families with diverse backgrounds. In addition, the use of AT devices may require extensive training and collaboration between the family members and the service providers. AT users and their family members may feel overwhelmed and reluctant to go through the training even when they do not understand the benefits of a new AT device and are cognitively challenged due to a technical complexity. Kling, Campbell, & Wilcox (2010) shows parents do not feel knowledgeable enough to utilize AT devices even though they believe AT is beneficial for their children's physical development. Also, early intervention professionals do not feel confident enough to train parents for the utilization of AT devices at home. To prevent the abandonment of the acquired devices, professionals need to put family needs as a priority over their own agenda when considering the selection and utilization of a new IoT-integrated AT for individuals.

CONCLUSION

This chapter discussed various IoT applications which is a certainty of future technology that will make positive differences in the lives of people with disabilities. Medical and technological advancement have made it possible for people with disabilities to enjoy the quality and longevity of their lives, which in turn has required healthcare and rehabilitation professionals to utilize various types of AT and IoT-integrated AT devices. Numerous IoT-integrated applications are being introduced into the AT market. However, the IoT being a relatively new development, has yet to see solid benefits of the IoT applications for people with disabilities. People with disabilities are a heterogeneous group and each individual case needs to be carefully examined when considering which applications should be utilized in under which circumstances. The field of special education has various AT service delivery models due to the AT federal legislation for children with disabilities. The healthcare field is faced with the following remaining tasks: including identifying or developing assessment instruments in order to identify which IoT-integrated AT applications will be used at which environment for which tasks, identifying funding sources and obtaining the devices, and securing qualified personnel for customization and implementation of the technology. The lack of valid information and unfamiliarity with the technology will make it difficult for professionals in healthcare and rehabilitation agencies to support people with disabilities in making informed decisions when adopting IoT-integrated AT applications. Research on the effectiveness of IoT-integrated AT applications that improve the quality of the lives of people with disabilities have a long way to go. However, the emergence of various IoT-integrated AT applications shed a promising light to the field; yet more attention should be given to security, trustworthiness, and reliability in the development and utilization of these applications. As noted by Busch et al. (2013), it is critical that technology-related disciplines promote enhanced privacy, security, and trust of people with various types of disabilities. User experience surveys involving all stakeholders - developers, users, family members, healthcare providers, and caregivers - is critical. Also, collaborative, coordinated, multidisciplinary efforts are a must to see the true intent of the above mentioned technological advancement in order to support people with disabilities as independent and productive citizens.

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KEY TERMS AND DEFINITIONS

Assistive Technology (AT): Technologies that assist individuals with disabilities in learning, communication, daily living, and accessing information.

Cloud Computing: A computing paradigm that relies on sharing computing resources such as servers, storage, bandwidth, and applications for an organization's computing needs.

Context-Aware Computing: Computing with the capacity to be aware of environments and their characteristics through sensor.

IoT Applications: Various IoT-based technologies developed to perform specific functions such as monitoring machines remotely, informing a caregiver of the real-time medical condition of a person with disability, etc.

Radio Frequency Identification (RFID): A system of electronic and computing devices which enables objects with embedded tag to be wirelessly identified and tracked.

Sensors: Wired or wireless devices used to monitor and alert change in environments such as temperature, light, sound, motion, etc.

Sensor Network: Sensors that are connected to one another to transmit signals to use for sensing, processing, and communicating via radio medium.

The Internet of Things and Assistive Technologies for People with Disabilities

Smart Homes: Homes with various features of ambient assisted living along with surveillance systems and control and optimization devices including lighting, window blinds, heating or alarm installations for people with disabilities.

Smart Sensors: Sensors with microprocessor that can be used for digital signal processing, data filtering, self-diagnosis, self-identification, and self-adaptation.

Chapter 3

IoT for Ambient Assisted Living: Care4Me – A Healthcare Support System

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ABSTRACT

Research activities on healthcare support systems mainly focus on people in their own homes or nurses and doctors in hospitals. A limited amount of research aims at supporting caregivers that work with people with disabilities in assisted living facilities (ALFs). This chapter explores and applies the Internet of Things to the ALF context. In particular, it presents the design, the implementation, and the experimental evaluation of Care4Me, a system supporting the daily activities of assistants. The requirements for designing and implementing Care4Me derive from a literature analysis and from a user study. The solution combines wearable and mobile technologies. With this healthcare support system, caregivers can be automatically alerted of potentially hazardous situations. Furthermore, inhabitants can require assistance instantly and from any point of the facility. The system was evaluated in two ways. The authors performed a functional test with a group of professional caregivers, and deployed the system in an ALF in Italy, collecting the opinions of caregivers and inhabitants.

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INTRODUCTION

One of the challenges that the healthcare sector has been facing in the last decade is how to ensure full coverage of professional care for those who require special attention (e.g., the elderly, people with disabilities, or patients with chronic conditions) containing the associated costs. To address this challenge, Ambient Assisted Living (AAL) systems have been researched extensively (Rashidi & Mihailidis, 2012). AAL is a term used to describe a set of technical systems, infrastructures, and services to support elderly people or people with disabilities in their daily routine. It allows an independent and safe lifestyle via the integration of information technologies within homes and residences. Research in the field of healthcare support systems is mainly focused on addressing two problems: improving the quality of life for people in their own homes, especially the elderly, and supporting nurses and physicians in hospitals. However, less research has been done about systems to support caregivers that assist persons with disabilities within nursing homes and on how to design such systems to be effective. To fill this gap, Aced López, Corno, and De Russis (2015) presented a series of guidelines for designing systems that could effectively support caregivers in tasks such as monitoring nursing homes inhabitants and attending to their assistance requests. These design guidelines derive from a literature analysis and from the qualitative analysis of a comprehensive user study carried out in three different Italian Assisted Living Facilities (ALFs) for people with physical and cognitive disabilities. ALFs are health and social care facilities with the aim of providing hospitality, welfare benefits, and recovery to people in mental or physical conditions of dependency. They ensure adequate living conditions for the inhabitants, appropriate for their dignity, by promoting the maintenance or recovery of their residual capacities and the satisfaction of their relational and social needs. Healthcare assistants are the only professional figures employed full time in such houses, typically, so their point of view is central in designing a system that successfully operates in a ALF. The authors of the guidelines conducted three focus groups with a total of 30 caregivers, first focusing on the needs of the healthcare assistants and the overall user acceptance of a new healthcare support system, then on the features and capabilities of the devices used for its implementation. They concluded that a healthcare support system should be designed taking into account issues such as portability, ubiquity, unobtrusiveness, and automatic detection of hazardous situations.

This chapter aims at applying these guidelines and other specific requirements to an effective solution for a healthcare support system. In particular, the authors present the design, the implementation, and the experimental evaluation of an Internet of Things (IoT) system, named Care4Me, capable of supporting the daily activities of healthcare assistants that operate in ALFs and compliant with the

guidelines set forth in the work of Aced et al. (2015). The requirements for designing and implementing Care4Me derive from a literature analysis and from a user study conducted with professional caregivers. The authors chose to adopt the IoT technology because this paradigm is being increasingly recognized: the potential of IoT can be used to enhance or at least to enrich healthcare support systems by sensing physiological signals ubiquitously and unobtrusively. As the name suggests, the IoT is the network of physical objects that are supposed to be always connected to the Internet with the aim of sharing services and information with other connected “things”. In addition to connecting people, anytime and everywhere, IoT connects humans to smart objects, and puts these objects at the service of humanity. The system presented here involves mobile and wearable technologies to improve the modalities to provide and require assistance. Through it, caregivers can be automatically alerted of potentially hazardous situations that happen to the inhabitants while these are out of sight. Furthermore, inhabitants can require assistance instantly and from any point of the facility.

The work was divided in several phases. First of all, the authors extracted the requirements from the study of Aced et al. (2015) and from the results of a user study with a group of professional caregivers. In this way, the authors based the design of the system on the needs of real users. Then, the solution was implemented and tested in laboratory. Finally, the system was evaluated in two ways: a) performing a functional test with a small group of professional caregivers, and b) deploying the system in an Italian ALF for 36 hours, collecting objective data as well as the opinions of the involved caregivers and inhabitants.

BACKGROUND

Within the AAL field, several systems, proposals, and investigations are present. However, as reported in the survey of Calvaresi et al. (2016), the domain of AAL is pretty new, and more studies are required. For example, most of AAL studies does not consider all the stakeholders that should be taken into account in a healthcare support system (e.g., the elderly, people with disabilities, caregivers, physicians, etc.). Some exceptions can be found, e.g., the CAALYX system (Rocha, et al., 2013), and the IoT infrastructure for AAL scenarios reported in (Dhor, Modre-Opsrian, Drobits, Hayn, & Schreier, 2010). Such systems propose monitoring systems to support all the people involved in the care of patients. Apart from these solutions, most of the healthcare support system in the AAL field focus only on elderly people. For instance, Verity (Winkley, Jiang, & Jiang, 2012) is an AAL platform for the monitoring of the elderly, which uses a wrist-wearable wireless sensor node and a mobile platform to form a remotely accessible body area network. Rashidi and Cook

(2013) present COM, a fully automated approach for discovering and monitoring patterns of daily activities of older adults in their smart home. Considering the same context, Suryadevara and Mukhopadhyay (2014), present a pervasive computing technology to determine the wellness of the elderly living independently in their homes, monitoring the use of household appliances using smart sensors. Other studies focus on building applications in structured environments, such as hospitals, to support medical and nursing staff only (Adamer et al., 2008; Sanchez, Tentori, & Favela, 2008).

According to another AAL survey (Acampora, Cook, Rashidi, & Vasilakos, 2013), most of the healthcare support systems found in the literature focus mainly on AAL in terms of Emergency Detection or Continuous Monitoring. Such systems, like AMON (Anliker et al., 2004) and CARMA (Lau et al., 2010), aim at enabling people with special needs to stay at home and to be monitored remotely by medical staff, rather than being hospitalized with the costs this entails. Many of these systems were implemented by exploiting intelligent environments (Dawadi, Cook, Schmitter-Edgecombe, & Parsey, 2013) and mobile technologies (Bisio, Lavagetto, Marchese, & Sciarrone, 2015; Lau et al., 2010). Wearable technologies have also been researched as possible enabling technologies. Wearable systems can be broadly defined as miniature electronic devices unobtrusively embedded in outfits as part of clothing or as an accessory. Such systems should be usable without interfering with the user's action in the physical world (Altakouri, Kortuem, Grunerbl, Kunze, & Lukowicz, 2010; Anliker et al., 2004), thus making them attractive for various applications. One of the most popular applications of wearable technology is the monitoring of physiological parameters, as demonstrated by the recent spread of commercial devices and gadgets targeting the sport and recreational markets. However, few studies are available in the literature regarding the usage of wearable devices as core components of complex healthcare systems. Some exceptions can be found in system such as WearNET (Lukowicz, Junker, Stäger, von Büren, & Tröster, 2002), AMON (Anliker, et al., 2004), and in more recent tools that combine wearable and environmental sensing for long-term sleep studies, as in the work presented by Borazio and Van Laerhoven (2012).

In addition to the technologies used to implement a healthcare support system, a limited amount of AAL studies in the healthcare domain focuses on user needs and acceptance, rather than on the capabilities of the system and/or the devices. Among these studies, for example, the list of properties desirable in a commercial healthcare system reported by Bhadoria and Gupta (2013) is included. Mayora et al. (2013) present a reflection on non-functional requirements that are key in the development of technological solutions for personal health systems. Such requirements come from patients, since the system is intended to directly support them in the treatment of bipolar disorder. Altakouri et al. (2010) presents a Wizard-of-Oz

study at a geriatric care ward, conducted to verify the resulting hypothesis from some semi-structured interviews to nurses. Some similar interviews are also conducted in the study about elderly at home presented by Zulas, Crandall, Schmitter-Edgecombe, and Cook (2012), but the number of nurses is low, less than ten.

Many of the healthcare systems found in the literature aim at supporting doctors, patients, or the elderly, typically in a hospital or at home. Unfortunately, few studies and healthcare applications aiming at supporting healthcare workers in nursing homes are present. Among them, presented systems often are not based on IoT or wearable technologies (Bhadoria & Gupta, 2013), or aim at supporting specific activities only, such as the system for activity recognition to support nursing documentation realized by Altakouri et al. (2010). Due to the limited amount of research, design recommendations for systems in the context of assisted living facilities are very limited. Moreover, the few recommendations available in the literature mainly identify the needs of persons with disabilities, neglecting the needs of their caregivers, even if Beeber et al. (2014) demonstrated that the quality of assistance in ALFs (and therefore the inhabitants' quality of life) is highly related to caregivers' attitudes and to their perception of their working environment. The recommendations reported by Morrison, George and Mosqueda (2008), for instance, enumerate some practical changes in primary care practices that can enhance disability care, such as promoting positive images of disability (e.g., by hiring staff members with disabilities) and easier ways to contact the staff. In the work presented by Aced et al. (2015), the authors propose a series of guidelines for designing systems that could effectively support the caregivers of an ALF in their daily work. These guidelines are derived from the results of group interviews with the caregivers of three different Italian ALFs managed by the Cooperativa Sociale P.G. Frassati. The purpose of the focus groups consisted in identifying the needs and concerns that healthcare workers in ALFs have, understanding how they tackle problems and difficulties in their daily work, and how technology can help or support them. The interviews were held in three 90-minutes sessions that involved 30 professional caregivers, 22 female and 8 male, with different years of expertise.

DESIGNING HEALTHCARE SUPPORT SYSTEMS

The Care4Me system stems from the guidelines reported by Aced et al. (2015); this section summarizes the most relevant points extracted from that study. The goal of such a study was to understand the needs and concerns that caregivers of assisted living facilities have, how do they currently tackle problems and difficulties, and how technology can help or support them in their daily work.

The addressed research questions were the following:

1. How can the introduction of a healthcare support system based on mobile and wearable technologies support caregivers in their daily activities within an ALF?
2. What are the current needs, concerns and desires that caregivers of assisted living facilities for people with disabilities have?
3. What particular needs or issues can prevent (or foster) the adoption of any mobile/wearable device to support caregivers' daily activities?

Aced et al. conducted three focus groups, one for each ALF. The focus groups took place in the nursing homes to enable better understanding of the context, needs, problems, and possible already used tools. A set of semi-structured interview questions were posed, focusing on caregivers' daily activities, related problems and wishes. Participants were also asked to exemplify and expand on pain points, when needed, to provide a starting point for open discussion concerning different aspects of their experience. Previous studies mainly start from technological aspect and propose only a final evaluation of the system, focusing on validations driven by a small number of doctors and nurses (Anliker et al., 2004; Adamer et al., 2008; Zulas, Crandall, Schmitter-Edgecombe, & Cook, 2012). Aced et al., conversely, decided to interview a larger number of healthcare assistants to gather more comprehensive requirements. The interviews were held in three 90-minutes sessions that involved 30 professional caregivers, 22 female and 8 male, with different years of expertise.

The first part of this section reports the context that emerges from the user study, describing the involved ALFs and the daily routines of caregivers and inhabitants. The second part of this section then summarizes the guidelines found by Aced et al. for designing effective solutions of healthcare support systems.

Context

Two of the nursing homes reported in the paper accommodate people with various degrees of mental disorders, while the third one houses people with motor impairments. Each ALF hosts around ten people, and in each facility assistance is guaranteed 24/7. During the day, two healthcare assistants are always present in the nursing home, performing various activities, from personal assistance (e.g., helping the inhabitants to brush their teeth), to drug administration, or help in housework (e.g., cooking or doing laundry). A nurse is present one hour per day, every day, while a doctor is available on request, only. During the night, one caregiver is present in the facility, performing some house-works and running ward rounds.

All the ALFs involved in the study share some characteristics. They have a backyard, a fully equipped kitchen, a laundry, an infirmary, a living room, a space used as an office by caregivers and single or shared bedrooms for the inhabitants. In

particular, two facilities have two floors, one for the bedrooms of the inhabitants, and one for kitchen and the living room, and all the involved nursing homes have several areas from which it is difficult to hear what happens in the inhabitants' bedrooms. Moreover, within the three ALFs, no place allows caregivers to simultaneously see all the inhabitant bedrooms.

Common needs emerged from the caregivers across the three focus groups, with some minor differences due to the diverse type of disabilities. In fact, people with motor disabilities perform most of their activities inside the ALF, while many activities carried on by persons with cognitive disabilities are situated outside the house. However, the inhabitants with mental disorders have to be closely monitored, because they may suffer from epileptic seizures, or they may try to break or escape the ALF. Instead, the inhabitants with motor disabilities require assistance in order to perform daily activities that they would not be able to carry out otherwise.

Caregivers perform daily activities in assisted living facilities following a pretty fixed schedule. In this way, caregivers remember more easily the routines of each inhabitant and all the tasks that need to be carried out. These tasks include bathroom turns, medication, and diets. Routines are structured in such a way they indicate the caregivers what to do, with which inhabitant and at what time. For example, an ALF reported in the paper has a collective routine for establishing the order in which the inhabitants are woken up and transferred to their wheelchairs. Healthcare assistants, at the end of their shift, must compile a form reporting relevant issues and performed activities, on paper. Schedules are very useful to organize and simplify daily activities. However, caregivers encounter difficulties with some tasks that are out of the routine, such as one-off appointments or temporary drug administration. In some cases, in the shift change, caregivers leave a post-it note to their colleagues to highlight some news (e.g., a guest got a flu) and changes in the expected activities (e.g., the swimming pool is unexpectedly closed, today).

ALF inhabitants can request the assistance of a caregiver by calling her by voice or using buzzers that are in fixed positions around the house. One buzzer is present inside each bedroom (near the bed, typically) and another is located in each bathroom, as required by the Italian law. However, there are situations in which caregivers cannot hear the inhabitants, or where the buzzer is not reachable. These missed calls constitute the main problem for the healthcare assistants and, at the moment, this is an aspect that they consider not addressed. In fact, monitoring nursing homes is not an easy task, even in small structures of 10 or 15 residents, because caregivers are not always able to keep an eye on every resident, e.g., while they sleep or go to the bathroom. Since it is not possible to monitor the inhabitants with video-cameras or by other means that could be privacy invasive, the only method with which caregivers count to monitor the residents is the ward round. A ward round is a simple method for monitoring residents in nursing homes which consists of periodically visiting

every resident to make physical visual confirmation of their status to determinate if assistance is needed. However, if the structure is large enough or if the number of people to be monitored is high enough, ward rounds may be not very effective. Furthermore, the use of the current system for assistance, composed of buzzers and light panels, is a source of discomfort: the loud noise produced by an alarm can upset the peacefulness of the facility.

Each caregiver brings with her a cordless phone, multiple keys and, in some cases, her personal smartphone. ALF inhabitants with cognitive disabilities, unlike those with motor impairments, do not own any technological tool, such as smartphones, tablets, or computers. Caregivers and inhabitants' parents promote this situation, because of the possibility that such objects might be stolen, broken or forgotten outside the nursing home.

Guidelines

The results of the study of Aced et al. are 10 guidelines for designing a healthcare support system for an ALF. These guidelines, numbered from GL1 to GL10, are reported in Table 1.

In the focus groups, caregivers express the desire to bring with them less “objects” as possible: they need to have their hands free to be able to readily help and attend any person who requires their assistance (GL1). For this reason, the devices used by a healthcare support system should be easily taken around the assisted living facility by the caregivers, without representing a source of discomfort (GL3). Furthermore, the system should not introduce unnecessary devices for the inhabitants, because most of them do not actually own any technological tool, such as smartphones or tablets. Finally, all the objects and tools used by the caregivers should be resistant to water and shocks, given the fact that their attention has to be directed to the ALF inhabitants and not to devices integrity.

An important issue that emerged during the focus groups concerns the modalities used by inhabitants to consciously require assistance. Nowadays, they have to call caregivers by voice or using a buzzer in some fixed locations inside the environment. However, there are situations where caregivers cannot hear the inhabitants calls, or where the buzzer is not reachable. In fact, inhabitants may be outside the house, away from caregivers (e.g., in the backyard), or they may have fallen out of the wheelchair, unable to use the buzzer. These missed calls are a problem that currently is not tackled, but that caregivers perceive as “really important” since they are not able to timely intervene. For this reason, a healthcare support system should support caregivers and inhabitants regardless of their location inside the facility (GL2). Furthermore, the buzzer and its usage are sources of discomfort, in particular for the loud noise produced to notify a request for help. Thus, the system

Table 1. Guidelines for designing a healthcare support system

Number	Guideline	Description
GL1	Interfaces for operating in the periphery of caregivers' attention	A healthcare support system should exploit devices and interfaces that can be operated hands-free and without engaging caregivers' full attention in a stressful manner
GL2	System ubiquity	A healthcare support system should support caregivers through their daily activities, regardless of their location inside the assisted living facility
GL3	Portability of devices	The devices used as part of healthcare support systems should be easily taken around the assisted living facility by the caregivers, without representing a source of discomfort
GL4	Unobtrusiveness of the assistance request mechanism	A healthcare support system should offer to the inhabitants a mechanism for requesting caregivers assistance that does not disturb other people within the assisted living facility
GL5	Verification of assistance provision	A healthcare support system should verify that for each request received from inhabitants of the ALF, the proper assistance is actually provided
GL6	Self-direct caregivers' attention to potentially hazardous situations	A healthcare support system should be able to indicate to the caregivers potentially hazardous situations in which the inhabitants may be involved without any explicit request
GL7	Emergency call option for caregivers	A healthcare support system should allow the caregivers an immediate way to call for help in case of necessity, either manually or automatically
GL8	In situ form filling	A healthcare support system should allow caregivers to fill notes and forms digitally around the facility, even if not at the end of the shift and in the office, to prevent them from forgetting the information to write in
GL9	Effective management of reminders	A healthcare support system should manage the caregivers' routines and remind them effectively about special events or off plan tasks
GL10	Basic smart home capabilities	A healthcare support system for assisted living facilities should provide the caregivers with home automation capabilities to facilitate the management and operation of the facility building

Source: Aced et al. (2015)

should offer to the inhabitants a mechanism for requesting assistance that does not disturb other people within the assisted living facility (GL4).

However, caregivers fear that the implementation of new systems instead of the buzzers could negatively affect the quality and efficiency of the assistance that they provide to the inhabitants. In fact, there is a fear of increasing the number of missed calls by having the possibility of ignoring a request for help. For this reason, a healthcare support system must be able to confirm that at least one caregiver is properly addressing the assistance requests, as soon as possible (GL5).

A related problem in ALFs is how to monitor the inhabitants while they are out of sight in order to assist them in time, in case of need. In fact, inhabitants with

either mental or physical disabilities may need quick assistance, but may not be able to request it, e.g., they may be in the middle of an epileptic seizure. Until now, the problem has been tackled by running overnight ward rounds to constantly check for potentially hazardous situations, while during the day it has not been tackled at all. Caregivers need a healthcare support system that helps them to monitor the ALF inhabitants when they are out of sight. Such a system should be able to recognize when some hazardous situation is taking place and then notify the caregivers (GL6). The accuracy of the detection process is not crucial: according to the caregivers, “false positives” are better than “false negatives”.

Regarding the schedules of daily activities and the paper work performed by the caregivers at the end of their shifts, the operations can be easily converted in digital format and integrated in an information system, maybe shared between more ALF structures, to provide complete information about the personal history of the nursing home inhabitants, if needed. In a similar way, the post-it notes that healthcare assistants exchange during the shift changes can be easily converted in “electronic post-it” notes and delivered to the right caregiver (in a suitable moment, possibly) by an ubiquitous system (GL8 and GL9).

As reported in the description of daily’s routine within an ALF, during the night only one caregiver is present in the facility. The reason is that during the day there are more activities to be carried out and the inhabitants require more attention than during the night, while they are asleep. However, caregivers fear that something bad could happen to themselves and no one could help them while they are alone (without a colleague nearby). Caregivers worry for themselves but also for the ALF inhabitants, because if a hazardous situation occurs, the inhabitants could suddenly remain without anyone to assist them. In the same way that caregivers expressed their desire to have “something” to allow the inhabitants to call them effectively in case of need, a healthcare support system has to provide some mechanisms to support caregivers when they are alone (GL7).

A common topic across the focus groups that was the need of better ways to control and operate the ALF building. Caregivers pointed out that it is very difficult to control the temperature of the facility in such a way that everyone is happy. Another issue related with the operation of the ALF building is opening and closing doors. In general, all doors are kept locked and the caregivers have to carry around a big bundle of keys. This situation is not comfortable, especially with regard to the main door. The main door, that gives access to the house, should be closed to prevent the inhabitants to escape, though cannot be locked for safety reasons. For now, the problem has been addressed with some bells that ring when the door is opened, but it is clear that this is not a sustainable solution. For this reason, a healthcare support system should use some Smart Home technologies to meet all other requirements of assisted living facilities (GL10).

Requirements Extraction for Care4Me

Starting from the general guidelines for designing healthcare support systems presented above, that are applicable to general AAL systems, for the Care4Me system some more specific requirements have been defined. Such requirements also cover the technical constraints, that will allow to define a specific hardware and software architecture suitable for deployment in the ALFs. While the general guidelines derive from previous works, systems requirements are described for the first time in this chapter. Requirements definition was conducted through a user study. Such a study was performed with a group of professional caregivers. The goal was to identify and adapt a subset of the general guidelines, applicable to the Care4Me scenario, yielding the specific set of requirements. In addition, starting from the expectations of the interviewed caregivers, the set of Care4Me requirements was expanded.

User Study

The user study in the requirements extraction phase was performed in one ALF for people with physical disabilities managed by the municipality of Turin. The participants were eight caregivers, all female, with different years of expertise. The study consisted in the analysis of the answers of the participants to a questionnaire of 12 questions. The questions were about two hypothetical scenarios describing two use cases of a possible healthcare support system.

The first scenario (Scenario 1) takes place in an ALF for people with mental disabilities. First, the scenario describes how the system works. Then, it presents a use case of a caregiver that is able to assist in time one of the ALF inhabitants thanks to a notification sent by the system after detecting automatically a hazardous situation. Among the questions of the questionnaire, the participants were asked to rate how useful they thought the system was, from 1 (“Not useful at all”) to 5 (“Very useful”). The average rating for the system usefulness was 4.8 with many positive comments.

Scenario 1: Maria is a caregiver that has been assigned to the night shift of a nursing home at the outskirts of the city. She has 5 residents to care of, distributed in a two floor structure where they live. One of the patients, Pino, suffers from occasional epileptic seizures and must be attended in the shortest possible time once a seizure starts. Maria does not have to make ward rounds to check every resident conditions, including Pino’s, because all of them use a wristband that is continuously measuring acceleration and sending it to an intelligent system. Such a system is able to process such acceleration readings to determine if something with them, and point it to Maria. As soon as Maria is notified she

reads the message and knows where to go and who may be the one needing her help. When she arrives to the resident, she deactivates the alarm by tapping the resident's wristband and checks the situation. If she needs help from someone else she can just tap her own wristband and a predefined contact will be asked for help.

Last week, Pino started to shudder while sleeping and Maria that was in the coffee room was notified that "something" was happening with Pino at his room. She immediately reached him and attend him on time. Yesterday, Pino go up at the middle of the night and Maria was notified again that "something" was happening with Pino, so she checked that he only woke up to drink and went back to her office.

The second scenario (Scenario 2) takes place in a nursing home for people with physical disabilities. First, the scenario describes how the system works. Then, it presents a use case of a caregiver that reaches an inhabitant that have requested assistance through a wearable device and presents what happens when multiple alerts are issued. Again, the participants were asked to rate how useful they thought the system was, with the same scale adopted before. This time, the average rating was only 3.5. The general comments were quite positive, while two volunteers suggested that requesting assistance through a device could be "less personal" than doing it by voice.

Scenario 2: Carlo works in a nursing home for people with motor disorder that hosts 10 people distributed in a two floor structure. Until a month ago, inhabitants could call a caregiver in case of need thanks to a buzzer in a fixed position of their room, only. Recently, it has happened that an inhabitant has fallen out from the wheelchair in the backyard in such a way that is unable to operate any buzzer, not even the horn embedded in the wheelchair. The inhabitant was rescued after an hour, when a caregiver noticed her absence. For this reason, caregivers decided to adopt a technological system to mitigate this type of situations. With such a system, all inhabitants have a wearable bracelet with a button for requesting help, and all caregivers have a wearable device for managing the request for help of the inhabitants.

Recently, Carlo has received on his device a request for help from Gloria, one of the inhabitants of the nursing home. Carlo reached Gloria and helped her to open the door of the computer room, in which Gloria wanted to enter. In the same time, Carlo was notified of a request from another inhabitant. Another caregiver accepted the request for help, and Carlo was notified of the situation on his wearable device.

The answers of the questionnaires highlight that caregivers are primarily interested in the inhabitants' safety. In fact, the main goal of the caregivers is to provide

assistance every time is needed. In addition, when asked about the acceptance of the hypothetical healthcare support system, according to the described scenarios and their own experience, the eight healthcare assistants expressed very positive comments, especially about the choice of a wearable device like a wristwatch instead of smartphone or similar. In term of guidelines existing in literature, the focus is on issues such as portability of the devices, usability of the system, and real time monitoring of the inhabitants' conditions. Other guidelines (e.g, relating to smart home capabilities) are secondary for the caregiver, and, for this reason, were not considered.

Starting from these considerations, and thinking to the ALFs context, a general goal was the need of designing a ubiquitous system allowing new methods for requiring and providing assistance. To accomplish this need, the authors chose to adopt the IoT technology, and defined specific requirements about the communication of the involved devices.

Requirements of Care4Me

The requirements to design and implement Care4Me, numbered from R1 to R10, are reported in Table 2. They summarize the most important aspects followed to design and implement the system.

The first requirements regard the choice of the devices to be used. The system should be designed taking into account issues such as ubiquity and portability (R1 and R2, derived from GL2 and GL3). It is clear that a natural consequence is the use of mobile and wearable technologies. In particular, all the observations extracted from the focus groups can be easily addressed with wearable devices. The robustness of the used devices is another important requirement (R3, derived from GL3). The devices should be resistant to water and shocks, as reported in all focus groups.

Five requirements were defined to design the modalities for requiring and providing assistance. First, the system should allow the inhabitants to instantly require caregiver assistance (R4, derived from the results of the user study). In addition, the system should offer an automatic detection process of hazardous situations, at least for what concerns epileptic seizures and falls, two of the most common problems suffered by inhabitants (R5, derived from the results of the user study and from GL6). The system should confirm that the assistance requests are addressed properly by at least one caregiver (R6, derived from GL5), and the new mechanism for requesting caregiver assistance should not use noising buzzers. Indeed, the system should not disturb the peacefulness within the assisted living facility (R7, derived from GL4). The last requirement about the assistance mechanism is specific for the caregivers.

Table 2. Requirements followed in the design of the system

Number	Requirement	Description
R1	System ubiquity	The system should support caregivers through their daily activities, regardless of their location inside the assisted living facility
R2	System portability	The used devices should be easily taken around the assisted living facility by the caregivers and the inhabitants, without representing a source of discomfort
R3	Robustness of the devices	The used devices should be resistant to water and shocks
R4	Smart assistance	Thanks to the system, an inhabitant should be able to instantly require the caregiver assistance
R5	Automatic detection	The system should be able to detect potentially hazardous situations in which the inhabitants may be involved without any explicit request. Caregivers should be alerted without the need of constantly running ward rounds or using privacy invasive methods (e.g., video recording)
R6	Assistance delivery confirmation	The system should verify that for each request received from inhabitants of the ALF, the proper assistance is actually provided
R7	Unobtrusiveness of the assistance request mechanism	The system should offer to the inhabitants a mechanism for requesting caregivers assistance that does not disturb other people within the assisted living facility
R8	Emergency call option for caregivers	The system should allow the caregivers an immediate way to call for help in case of necessity
R9	Reliability	The system must be intrinsically safe and reliable, in particular for what concerns the communication between the devices
R10	Internet availability	The system is an IoT solution and it uses the Internet as a communication network

The system should provide the caregivers with an immediate way to call for help in case of need (R8, derived from GL7).

Finally, the authors established two specific requirements regarding the communication between the devices. First, a general but not less important point concerns reliability (R9). The transmission of a request for help through the system must be reliable, because the ultimate goal of this system is to help caregivers to provide assistance to the inhabitants whenever it is needed. Second, the system requires an Internet connection (R10) because the system is based on the IoT technology and it uses the Internet as a communication network.

Summarizing, the authors defined 10 requirements to design a healthcare support system. These requirements concern issues such as ubiquity (R1), reliability (R9), and portability (R2). The authors chose to apply the IoT paradigm and use Internet as a communication network (R10). The goal is to improve the modalities for requiring and providing assistance through a new mechanism (R4, R5, R6, and

R7) that involves robust and wearable devices (R3 and R2). In particular, Care4Me introduces an anomaly detection process for the inhabitants (R5) and an emergency call option for the caregivers (R8).

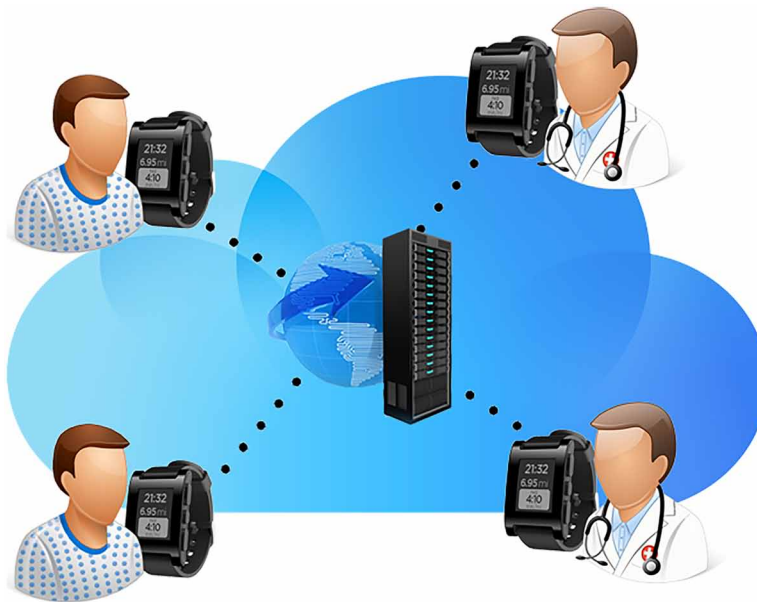
SYSTEM DESIGN

General Architecture

The general architecture of the system is shown in Figure 1. The system can be divided into two main areas: user devices and central server.

Each caregiver and inhabitant of the ALF is equipped with a wearable device, which ensures system portability (R2). Thanks to the wearable devices, users can use the system regardless of their location inside the ALF (R1). Inhabitants are monitored through their wearable accessory, in particular for what concerns seizures and falls (R5). Furthermore, they may require assistance voluntary and instantly, from any point of the facility (R4). Through the wearable devices, caregivers are able to manage the help requests. In this way, the unobtrusiveness of the assistance request mechanism is ensured (R7).

Figure 1. System architecture



The solution provides a central server in charge of managing the overall system. In partnership with a relational database, the central node performs some important operations, such as user management, authentication process and persistence of information. Furthermore, the server manages the communication between the devices. In fact, in Care4Me none of the wearable devices interacts directly with the others. To better understand the communication process, think of an inhabitant who wants to get help: through her wearable device, she can send a message to the server, which will propagate the information to all registered caregivers on duty, in the form of notifications.

Employed Wearable Devices

Care4Me uses smartwatches as wearable devices because they are more accessible than other devices one may carry (Raghunath & Narayanaswami, 2002), and, in addition, a wristwatch is ideally located for body sensors (Maurer, Rowe, Smailagic, & Siewiorek, 2006) and as a wearable display (Harrison, Lim, Shick, & Hudson, 2009). Moreover, in the case of inhabitants with mental disabilities who do not accept anything that looks out of the ordinary, the form factor of a common object like a wristwatch is more than appropriate. Obviously, smartwatches should satisfy the defined portability and robustness requirements.

Use Cases

The behavior of the system can be described through three use cases:

1. Voluntary request of an inhabitant.
2. Automatic request of an inhabitant.
3. Request of a caregiver.

Through her smartwatch, an inhabitant can voluntary request assistance (use case 1). The same wearable device monitors the conditions of the inhabitant. It triggers an automatic request for help (use case 2) in case of falls or seizures. As shown in Figure 3, a notification is immediately sent to all caregivers on duty, which will display on their smartwatches the type of the problem and the involved inhabitant. The system, in particular for what concerns the monitoring of seizures and falls, is not designed to accurately identify potentially hazardous situations, but to detect some anomalous motion patterns. In other words, “false positives” are better than “false negatives” for this solution. Healthcare assistants required this type of behavior, since they prefer having to handle a false alarm than missing one.

Figure 2. Use cases 1 and 2

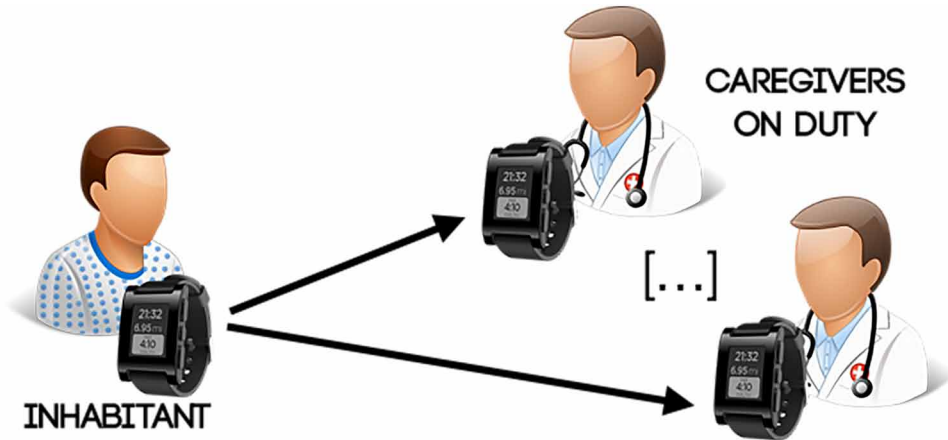
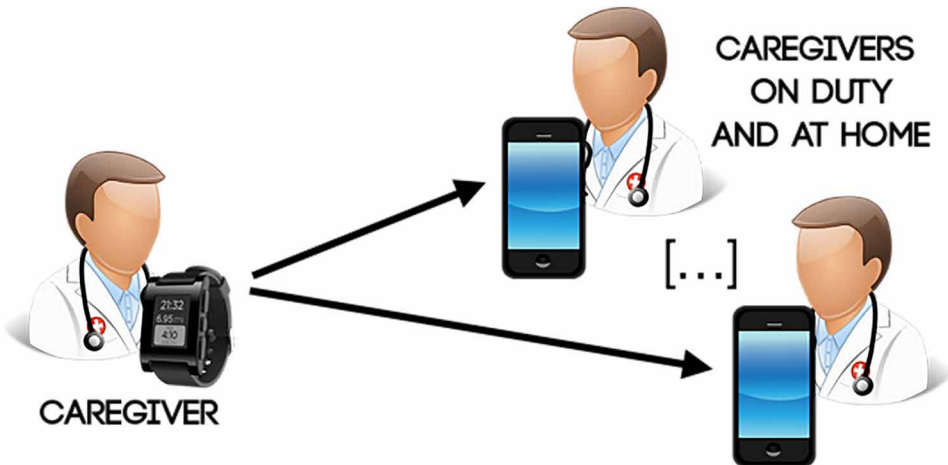


Figure 3. Use case 3



In the last use case (use case 3), caregivers can contact their colleagues in case of need, even those at home (Figure 3). Through their smartwatches they can send a notification to all other healthcare assistants, even those at home. In this case, in order to instantly catch the attention of all caregivers, notifications are shown on their smartphones.

The system primarily focuses on the assistance for inhabitants. In particular, the first two use cases are composed of three phases:

IoT for Ambient Assisted Living

1. Generation of the request.
2. Acceptance of the request.
3. Termination of the request.

Phase a: Generation of the request.

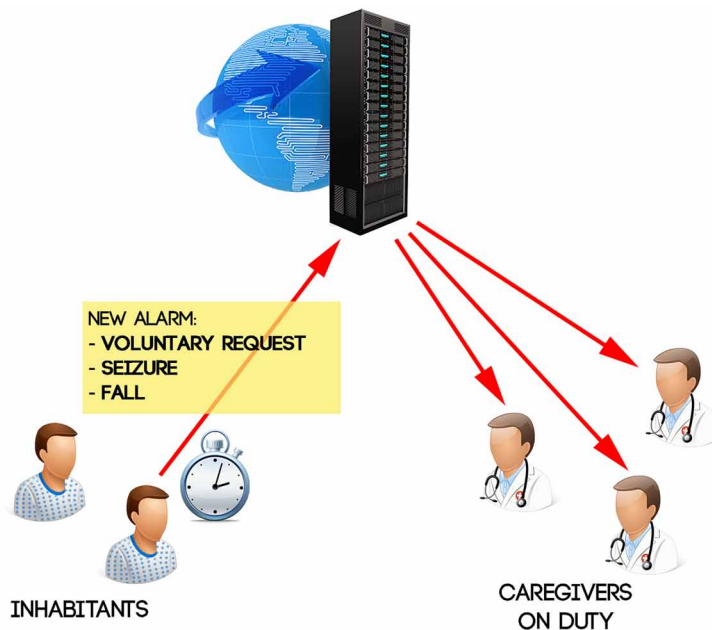
The generation of the request is the first step in the assistance process. In this phase, an inhabitant reaches all the caregivers on duty with a notification (Figure 4).

In detail, if the smartwatch of the inhabitant detects a request for help (thanks to the monitoring, or after a voluntary request), it generates an alarm and sends it to the server. The server interprets the received message and propagates the information to the caregivers on duty. The smartwatch will periodically resend the alarm until the request is terminated.

Phase b: Acceptance of the request.

The acceptance of the request is the second phase of the assistance process. Thanks to the generation of the request, all caregivers on duty are informed of the danger situation. In this phase, at least one caregiver should take charge of the request

Figure 4. Generation of the request



through her smartwatch (Figure 5). In this manner, all other healthcare assistants are informed that someone is taking care of the inhabitant.

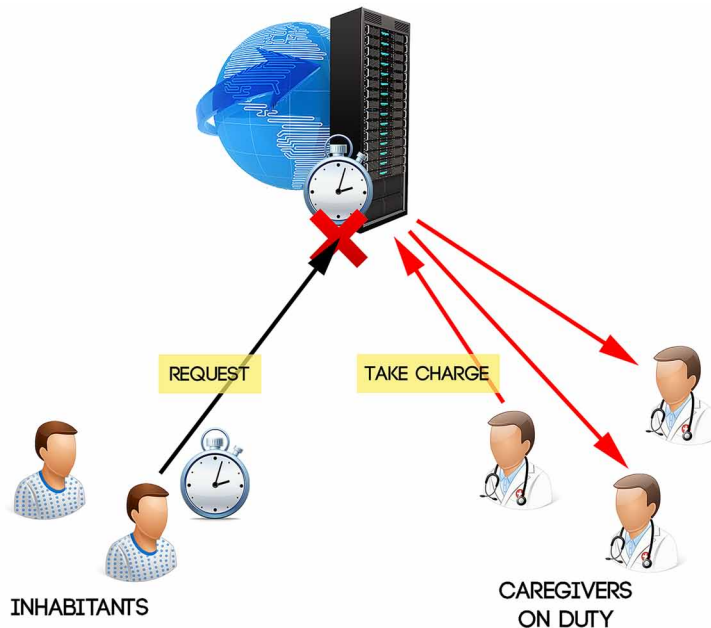
Specifically, the smartwatch of the caregiver that performs the acceptance of the request sends an acceptance notification to the server, which will propagate the information to all other assistants on duty. The server turns off the propagation of the request alarm temporarily. However, it checks that the termination of the request is carried out within a customizable timeout time; otherwise, it resumes the alarm signaling.

Phase c: Termination of the request.

The last phase of the assistance process is the termination of the request (Figure 6). With this phase, a caregiver can stop the alarm signaling and close the request.

To terminate the ongoing alarm, the caregiver who has accepted the request has to press a button on the inhabitant's smartwatch. In this way, the system ensures that the proper assistance is actually provided. The termination is still accepted even if it comes from another caregiver. The system provides a proximity check to prevent accidental pressing and to ensure that the request of termination came from a caregiver. If the assistant is sufficiently close to the inhabitant, the smartwatch of the

Figure 5. Acceptance of the request



inhabitant sends the notification of termination to the server, and stops to periodically resend the alarm. The cycle of the request for assistance is finished.

Implementation

For what concerns the wearable devices for the inhabitants and caregivers, the designed system has been realized with Pebble smartwatches (Figure 7).

Unfortunately, these types of devices do not provide a way to directly connect to the Internet, but they need an associated smartphone or tablet to bridge the connection. Care4Me uses Android smartphones to perform this operation.

As shown in Figure 8, the elements of the system communicate with each other in several ways. A smartwatch is paired with its mobile device via Bluetooth. Mobile devices can reach the server through HTTP requests, while the same server can contact the clients asynchronously with the Google Cloud Messaging (GCM) service.

Devices for Users

The authors implemented four applications for users: two Pebble applications, one for caregivers and one for inhabitants, and the two paired Android apps. The Android

Figure 6. Termination of the request

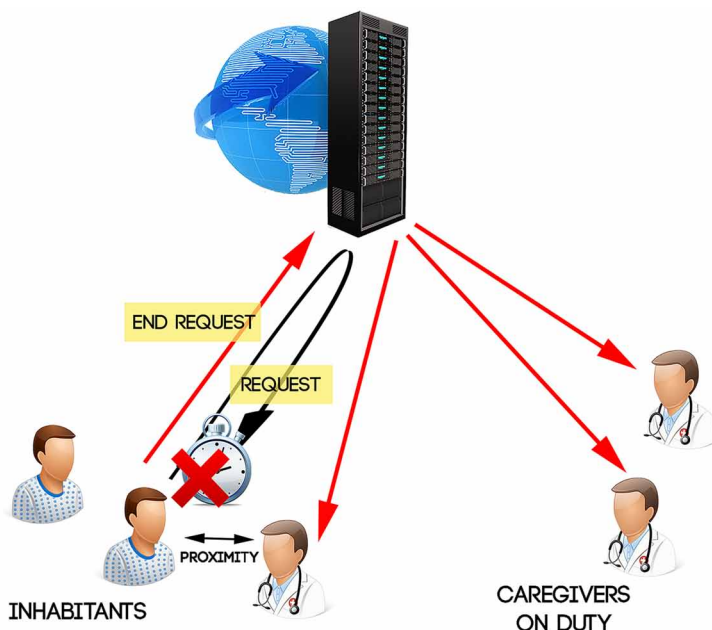
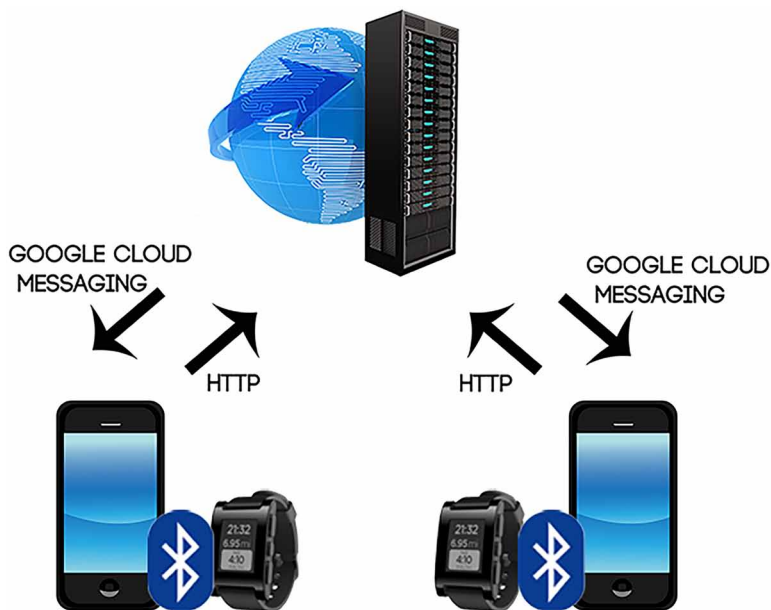


Figure 7. Wearable devices used in Care4Me



Figure 8. The communication between devices



applications for caregivers and inhabitants are quite similar. These applications are designed to be invisible for the user: they mainly work in background, except for the initial authentication. Perhaps, the idea is to allow caregivers to use their personal smartphones, and to hide the inhabitants' smartphones (e.g., in their backpacks or wheelchairs), making them inaccessible. The applications intercept messages and

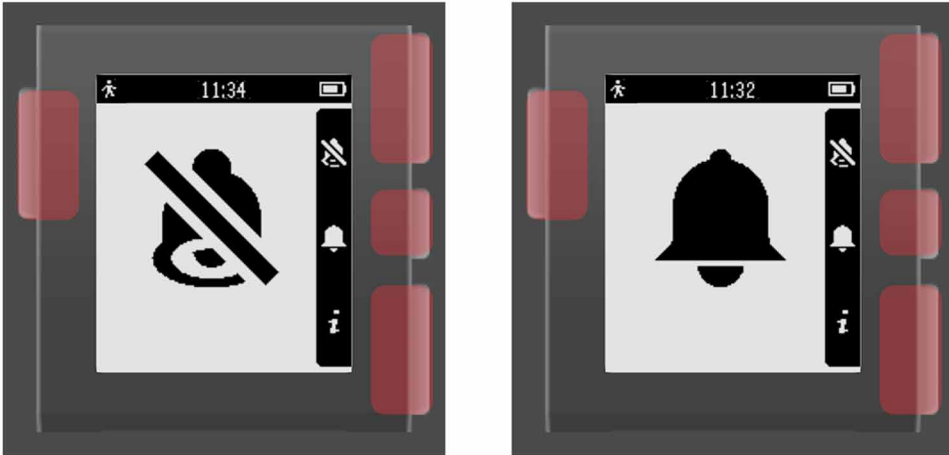
allow the communication, acting as intermediaries between the paired smartwatch and the server. Furthermore, they allow the Bluetooth Low Energy proximity check to ensure that the termination of an alarm is performed by a caregiver, only. To do that, the mobile device of a caregiver acts like a beacon to be discoverable from the mobile device of an inhabitant.

The implemented Pebble application for the inhabitant's smartwatch enables the voluntary request, and performs the monitoring of epileptic seizures and falls in background. In this way, even users that are not able to directly interact with the device can benefit from the system. The anomaly detection process is done through the on board accelerometer. The application continuously collects, processes, and analyzes accelerometer data in order to detect seizures and falls. Considering that the accuracy of the detection process is not crucial, Care4Me implements a simple algorithm based on some thresholds (e.g., acceleration peaks and acceleration average). In this way, the monitoring can be done directly on the smartwatches, which have low computational capacity. Thus, no accelerometer data are transferred between the devices, and the Bluetooth communication between the smartwatch and the paired device is not burdened with too many messages. The two main screens of the application are shown in Figure 9.

The application for the caregiver's Pebble presents a richer user interface. It is designed through a series of menus covering the main user cases: caregivers can view the ongoing alarms, communicate to their colleagues the availability to serve a request, and view all the alarms that they have taken under their control. From the same application a caregiver can send a request for help to her colleagues (use case 3). Some screenshots of the application are shown in Figure 10.

Figure 9. The Pebble application for the inhabitant



Figure 10. The Pebble application for the caregiver

Central Server

The server was implemented as a Java Enterprise Edition web application. The application has been developed through the Model View Controller (MVC) pattern, which ensures modular and reusable code.

The main component of the server in Care4Me is a RESTful web service. Representational State Transfer (REST) is an architectural style that specifies constraints, such as a uniform interface, to increase the system performance, scalability, reusability, and maintainability. In the REST style, data are considered resources and are accessed using Uniform Resource Identifiers (URIs). The resources represent the model of the application and they are managed by using a set of simple, well-defined operations. The REST architectural style is specific for a client/server architecture and is designed to use a stateless communication protocol. The RESTful web service manages the overall system and allows communication between devices. All smartphones contact the server through an HTTP request to communicate something to other devices. In agreement with the REST architecture, considering the type of the request and the URL, the server maps the request on a specific entity (or collection of entities) that describes the system environment. The web application acts on the model, applies the application logic, and produces a response for the client. Eventually, it can send an asynchronous message to other users through the GCM service.

In addition, the web application offers a web site that caregivers can use to administer the system. Through it, they can manage user accounts, view the history of all the alarms generated in the facility, and manage alarms (e.g., force the

termination of an alarm) in case of system failures. Following the MVC pattern, the web site is the view of the server application. A screenshot of the home page is shown in Figure 11.

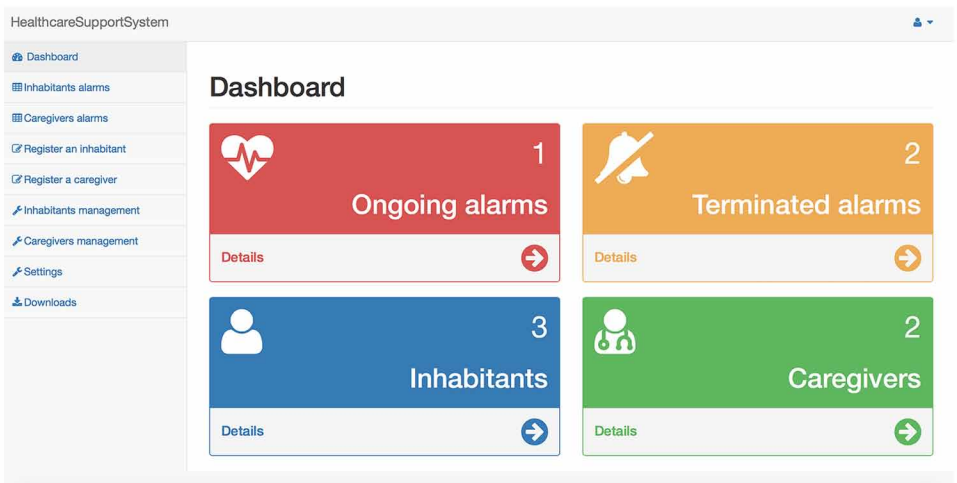
Experimental Evaluation

The experimental evaluation of the proposed system was performed along two directions. First, after some in-lab tests, the authors assessed the user acceptance and the perceived usefulness of the system with a functional test. In this phase, a group of healthcare assistants working in an ALF in Turin (Italy) tried the system. Second, the authors performed an operational test. The Care4Me was deployed in an ALF near Turin for 36 hours, collecting objective data as well as the opinions of the involved caregivers and inhabitants. Both tests were held in Italian, the native language of participants. In total, in the functional and operational tests, eleven people were involved. Nine of them were professional caregivers, while two of them were inhabitants with cognitive disabilities.

Functional Test

For measuring the user acceptance of Care4Me the authors performed a functional test with two caregivers working in one Italian ALF. This facility, called “Officina delle Idee” (Citta di Torino, n.d.) is managed by the municipality of Turin (Italy) and hosts six people with physical disabilities, only. It employs two caregivers during the

Figure 11. The web site for system administration



day, and one healthcare assistant during the night, similarly to the ALFs involved in the focus groups reported in the work of Aced et al. (2015).

Before the test, the authors distributed an initial questionnaire to the caregivers, to collect some information about their age, their experience in the field of healthcare assistance and their knowledge of technological devices. The participants were two professional caregivers more than 50 years old, each with more than 10 years of healthcare experience. Only one caregiver was familiar with mobile devices and PCs. Furthermore, neither was not familiar with wearable devices.

The functional test of Care4Me consisted in simulating some common scenarios, where the two volunteers acted like a caregiver and an inhabitant, respectively, equipped with one Pebble smartwatch each. The authors simulated a voluntary request from the inhabitant, with all the operations required for its termination, and the monitoring of hazardous situations. In this last case, the volunteer acting as the inhabitant moved his arm in such a way that the smartwatch detected an epileptic seizure. After the test, the authors gave a final questionnaire to the participants, in order to collect their opinions about the system, whose results are summarized in the “*Results*” section.

Operational Test

The last and more important experimental evaluation consisted of the deployment of the system in one ALF hosting people with cognitive disabilities managed by the Cooperativa Frassati for 36 consecutive hours. The aim of this test with real users was to demonstrate the usefulness of the system, both for caregivers and inhabitants.

The authors repeated an extended version of the functional test reported above with all the seven caregivers working in the RAF, as training for using the system. Table 3 and Table 4 summarize the profiles of the participants, while Table 5 and Table 6 summarize their experience with mobile and wearable devices, respectively. In this phase, four volunteers acted like two caregivers and two ALF inhabitants,

Table 3. Age of the participants

Age	Count
16-25	0
26-35	2
36-45	3
46-55	2
55+	0

Table 4. Year of expertise of the participants in their work

Years of Expertise	Count
<1	0
1-2	1
2-5	0
5-10	3
10+	3

Table 5. Experience of the participants with mobile technologies

Experience	Count
1 None	1
2 Little	3
3 Sufficient	2
4 Good	1
5 Excellent	0

Table 6. Experience of the participants with wearable technologies

Experience	Count
1 None	4
2 Little	2
3 Sufficient	1
4 Good	0
5 Excellent	0

respectively, while the rest of the group looked at the test. In addition to the operations for requesting and providing assistance, the authors introduced the caregivers to the administration web site. The training session was audio recorded for further analysis.

After the training phase, two inhabitants were equipped with a Pebble smartwatch and an associated smartphone, and the system was left running for 36 hours. The involved inhabitants were chosen by the caregivers of the facility, among those suffering from mild cognitive disabilities. The test covered three day-shifts and one night-shift, involving six caregivers. During the evaluation, the authors collected data about the usage of the system. Finally, a final survey was distributed to the involved caregivers and inhabitants. The results of this analysis are summarized in the “*Results*” section.

RESULTS

Results of the Functional Test

The first results about the user acceptance and the perceived usefulness of the system were extracted thanks to the functional test.

A direct observation of the caregivers’ actions during the test determined that, after a first approach with the system, the participants performed the required operations without any difficulty.

After the test, the participants expressed their first impressions in a brief discussion. They confirmed that the system might be useful, in particular for large facilities. However, they expressed the need of having a voice recognition feature in addition to the current methods for requiring assistance. In fact, not all inhabitants of the facility are able to use their hands to request assistance voluntary, because they suffer from severe physical disabilities.

A final questionnaire collected the qualitative opinions of the participants. Questions were based on a Likert scale with five responses ranging from “Not at all” (1) to “Very much” (5). As summarized in Table 7, both caregivers confirmed the usefulness of the system. They said that the system could improve their work and they expressed their satisfaction for the system portability, the intuitiveness of user interfaces, and system usability. Figure 12 reports the results of the functional test in a graphical form.

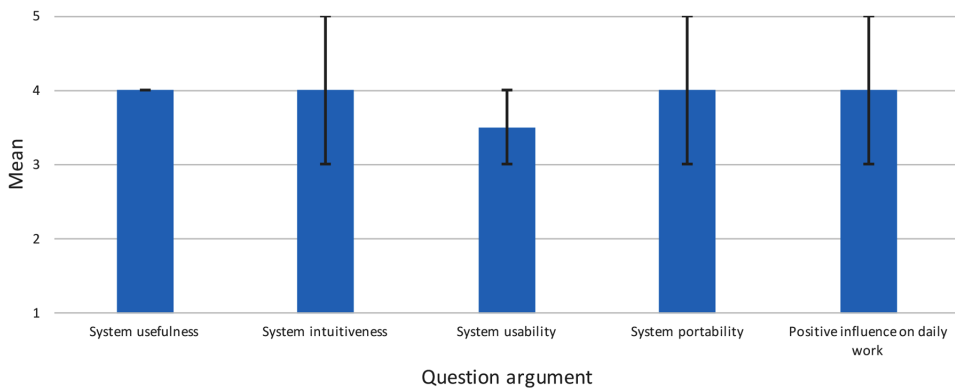
Results of the Operational Test

The operational test was the last and more important part of the experimental evaluation. The functional test was repeated as training for using the system. Also in this facility, after a first approach, the involved caregivers did not have any difficulty to learn how to use the system. Considering that the same behavior was observed in the previous functional test, a possible conclusion is that the system learning process is very fast.

Table 7. Results of the functional test

Question Argument	Mean	Standard Deviation
System usefulness	4.00	0.00
System intuitiveness	4.00	1.00
System usability	3.50	0.50
System portability	4.00	1.00
Positive influence on daily work	4.00	1.00

Figure 12. Graphical representation of functional test results



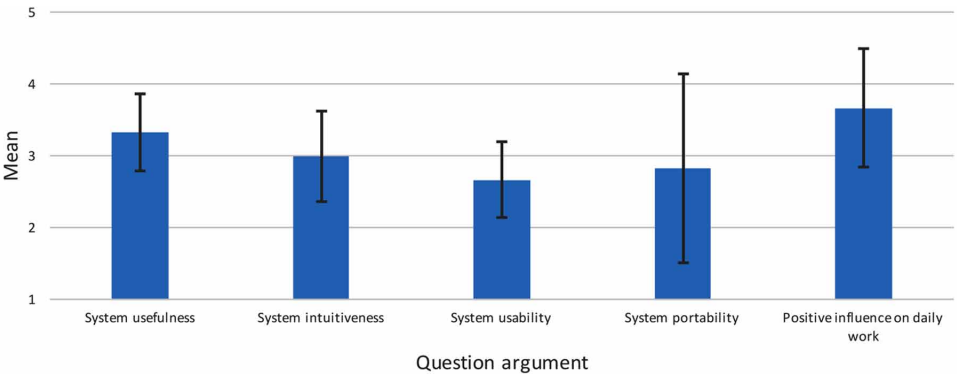
After the training of the system, the caregivers chose two ALF inhabitants in order to try the system for 36 hours. This operational test covered three day-shifts and one night-shift, involving six caregivers. However, the inhabitants used the system sparingly. For this reason, it is not possible to draw quantitative considerations from the generated data.

The final questionnaire compiled by the caregivers, an extended version of the one used for the functional test, gave more results. As reported in Table 8, the involved caregivers evaluated the system usefulness, usability, and portability on a Likert scale with five responses ranging from “Not at all” (1) to “Very much” (5), with positive results. Furthermore, they gave an opinion about the intuitiveness of the user interfaces and about the possible influence of the system in their work. Figure 13 reports the results of the functional test in a graphical form. In addition, three caregivers said that the modalities by which an inhabitant can request assistance are sufficient, while the other three would like more possibilities. Besides, three assistants were satisfied of the system features for providing assistance, while three confessed that they were not entirely satisfied.

Table 8. Results of the operational test

Question Argument	Mean	Standard Deviation
System usefulness	3.33	0.53
System intuitiveness	3.00	0.63
System usability	2.67	0.52
System portability	2.83	1.31
Positive influence on daily work	3.67	0.82

Figure 13. Graphical representation of operational test results



The questionnaires compiled by the two inhabitants confirmed their limited use of the system. The only relevant obtainable information is that an inhabitant would like a less complex wearable device, like a bracelet with a single button.

In conclusion, positive results were extracted from all the tests. With the in-lab tests, the authors demonstrated the system stability and reliability. Furthermore, both in the functional and in the operational test, all involved caregivers confirmed the usefulness of the system. They said that the system could improve the work in ALFs. The experimental evaluation was also useful to identify possible improvements, in particular for what concerns the system portability and usability. Unfortunately, the operational test involved two inhabitants, only, who used the system sparingly. For drawing more specific conclusions, advanced tests with more inhabitants are needed.

CONCLUSION

This chapter presented an IoT system capable of improving assistance requests and anomaly detection in an Assisted Living Facility through wearable devices. With this healthcare support system, caregivers can be automatically alerted of potentially hazardous situations that happen to the inhabitants while these are out of sight. Furthermore, inhabitants can require assistance instantly and from any point of the facility. Requirements for building such a system were extracted by taking into account the guidelines set forth in a previous study (Aced López, Corno, & De Russis, 2015), which conducted a series of focus groups with professional caregivers. The design of the system focused principally on portability and ubiquity. The system was implemented and tested in two phases. First, the authors performed a functional test with two professional caregivers to verify the user acceptance and the perceived usefulness. Second, the system was deployed in an ALF for 36 hours, collecting the opinions of the involved caregivers and inhabitants.

Future work will concern the increase of the possibilities to request assistance for inhabitants. In fact, people with severe physical disabilities hardly interact with wearable and mobile devices. In parallel, the authors are planning to generalize the solution to other devices, thinking at the progress of wearable devices. Without the need of having a paired mobile device to connect to the Internet, the system portability can be improved. Finally, an operational test with more caregivers and inhabitants is planned to draw more conclusions about actual system usage.

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Chapter 4

Hybrid Integration Technology for Wearable Sensor Systems

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ABSTRACT

Personalized and pervasive healthcare devices help seamlessly integrate healthcare and wellness into the daily life, independent of time and space. Silicon Integrated Circuit (IC) has been used in many advanced healthcare applications due to the compact size and ultra-low power consumption. Meanwhile, printed electronics (PE) is considered as a promising approach enabling cost-effective manufacturing of thin, flexible, and light-weight devices. A hybrid integration of IC and PE provides a new solution for the future wearable healthcare devices. In this chapter, firstly a customized bio-sensing IC is demonstrated, which can detect and process various bio-signals; secondly, the feasibility and performance of using inkjet printing technology as enabling technology has been examined for the fabrication of flexible bio-sensing devices. Finally, a wearable and flexible Bio-Patch is presented by leveraging hybrid integration of PE and bio-sensing IC. In-vivo test results show that the flexible Bio-Patch provides high quality ECG signal comparable with the one gained by bedside ECG machine.

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INTRODUCTION

Consistent with the global aging, many countries are facing challenges of elderly care. In the meantime, chronic diseases are becoming the major causes of death (European Commission Eurostat, 2011; Kung, Hoyert, Xu & Murphy, 2008) the prevalence of chronic diseases inevitably increases the total expenditure on healthcare and poses a grim challenge to the current healthcare systems worldwide (Zhang, Yan, & Poon, 2007; Chen et al., 2015). Traditional healthcare and well-being services are usually provided within hospitals or medical centers. People with chronic diseases as well as the patients in post-surgery state need continuous monitoring of their health condition, in particular the vital signs, until their health status becomes stable. Patients, as well as their families, also need to collaborate with their physicians to get informed about their status. Until now, most of the monitoring of the health condition of such people is usually accomplished within medical centers or hospital environments. As a result, measurements of vital signs and the corresponding diagnosis are carried out in controlled environments. However, this solution is costly and inconvenient for people with the need of routine checks, since the patients need to visit the hospital on a regular basis. Currently, several trends indicate that the healthcare is gradually moving from institutional care to a growing focus on the individual personalized healthcare at home (Dey & Estrin, 2011; Saranummi, 2008; Yang et al., 2014).

Connected and personalized healthcare help seamlessly integrate healthcare and wellness into people's daily life. Wearable medical or healthcare devices are the key elements that will catalyze the process to enable the paradigm shift from the clinic-centric approach towards a person-centric model. This paradigm shifts focuses on sustainable healthcare aiming to:

- Enable early detection for prompt medical care and healthcare;
- Improve the management of chronic diseases; and,
- Preventive medicine.

The relevance of this change is huge, and healthcare itself, as it can be seen, is changing. The prognosis of several conditions will improve considerably because of prompt intervention; the users will be empowered and more engaged in the management of their disease or even in maintaining their health with a healthy and active lifestyle. Hopefully in many cases this will happen just by wearing certain sensing devices or clothes.

With the developments in biomedical circuits and systems, nowadays, silicon based integrated circuits have shown great advantages in terms of compact size and ultra-low power consumption. As a result, they have been found in many advanced

medical and healthcare applications. In the meanwhile, printed electronics is considered as a promising approach enabling cost-effective manufacturing of thin, flexible, and light-weight devices. A hybrid integration of integrated circuits and printed electronics provides a promising solution for the future wearable healthcare devices.

State-of-the-Art of Current Wearable Healthcare Systems

In the last decade, wearable healthcare systems have drawn considerable attention from the research community and healthcare industry as it is pointed out by the numerous and yearly increasing corresponding research and development activities (Pantelopoulous & Bourbakis, 2010; Gatzoulis & Iakovidis, 2007; Lymperis & Dittmar, 2007). A variety of system prototypes and commercially available products have been designed and developed in recent years, with application scenarios of sports monitoring, elder healthcare, infants health monitoring, or smart rehabilitation etc., aiming at providing real-time or near-real-time feedback information regarding users' health condition, either to the users themselves or their family members or to a medical center or straight to a supervising professional physicians, while being able to alert in case of possible imminent health threatening conditions (Fredericks et al., 2015; Bonato, 2005, 2003; Raskovic, Martin, & Jovanov, 2004). A variety of commercially available products have been produced in the course of recent years, which are able to provide real time feedback on the users' physical conditions. Many manufacturers and healthcare companies like Philips Healthcare, Redding Medical etc. provide small, wearable, low power, and lightweight wearable systems for health-monitoring applications (Philips Healthcare, 2016; Nellcor, 2016; Agilent Technologies, 2016; Redding Medical, 2016). These wearables can provide real-time display of users' heart rate and blood oxygen saturation.

Wrist-worn devices have been developed to be easily applied on users' wrists to collect physiological or ambient parameters. Wristcare (Vivago, 2016) has developed a watch-like device, which monitors skin conductivity, skin temperature, and the user's movement. A similar device is offered by Myo, called Myo Armband (Myo armband, 2016). It is a gesture recognition device, worn on the wrist, which enables the user to wirelessly control paired smart gadgets in surroundings using various wrist and forearm motion patterns. It uses a set of electromyographic (EMG) sensors that sense bio-electrical activity in the forearm, combined with a gyroscope, accelerometer and magnetometer to recognize user's gestures which can be found quite useful for the postoperative rehabilitations for the brain disease related patients. Both aforementioned wrist-worn devices enable continuous physiological data collection outside the lab environment. Worn on the wrist or on the upper part of the arm, they utilize a unique combination of sensors allowing the user to gather physiological parameters such as skin temperature, body movement, muscle groups

activities, and galvanic skin response. Both devices include a wireless transmitter for communicating the collected data and possible alarms to a base station for further analysis or evaluation by a professional clinician.

Other commercially available wearable devices can be found include chest-worn belts for more accurate heart rate monitoring, which are usually applied in sports or physical training scenarios. MyZone (2016), Tickr (2016), and Garmin HRM (2016) provide smart chest straps which are capable to record users' heart rates in specific sports including running, rowing, cycling, or even swimming.

In the meantime, more new elements have been developed and brought into wearable systems, such as smart textiles or smart fabrics, which provide added value to the wearers (Perusquia-Hernandez, Chen & Feijs, 2015; Wang et al, 2015). Propelled by the recent technological advances in biocompatible textiles and materials, miniaturized bio sensing devices, micro- and nano-electronics, and hybrid integration technologies, the smart textiles based wearable healthcare system have showed its advantages in terms of high wearability and comfortableness to the users. Smart textile based wearable systems achieve a relatively high degree of reliability due to guaranteeing good contact between the skin and the sensing modules even when the subjects are in the motion (Pantelopoulous & Bourbakis, 2010). As a result, wearable healthcare systems which are based on vest or garment with biosensors integrated on are believed to have the potential to transform the future healthcare and constitute a new means to address the issues of monitoring and managing chronic diseases, elderly people, postoperative rehabilitation patients, and persons with special needs (Chen et al, 2015).

During the last years, the European Commission together with research funding agencies all over the world has implemented an intensive effort in the field of Smart Textiles and provided funding supports to a number of research projects covering a very broad spectrum of new concepts, new materials, new processes and new applications in the last decade. Among the implemented projects are some well recognized ones (EU Textiles, 2016):

- **AVALON:** Multifunctional textile structures driving new production and organizational paradigms in textile SME networks (Avalon, 2016);
- **Digitex:** Digital programmed jetting of fluids for multifunctional protective textiles (Digitex, 2016);
- **Inteltex:** Intelligent multi-reactive textiles integrating nano-filler based CPC-fibers (Inteltext, 2016);
- **Natex:** Aligned natural fibers and textiles for use in structural composite applications (Natex, 2016);
- **NoTeReFiGa:** Novel temperature regulating fibers and garments (NoTeReFiGa, 2016);

- **Microflex:** Micro fabrication production technology for MEMS on new emerging smart textiles/flexibles (Microflex, 2016); and,
- **PASTA:** Integrating platform for advanced smart textile applications (PASTA, 2016).

Due to the significant research and development activities in the field of smart textiles, research organizations and textile industries have been able to create innovative technology from scratch, and further push the technologies from several aspects (basic textiles and materials, interconnects, embedding electrodes, electronic and optical devices, systems worn on the body, etc), leading to the successful implementation of smart textiles into all sort of prototypes, systems, and applications.

Take the PASTA project (2016) as an example, which is a European Commission supported project, aiming to bring electronics and textile closer together to realize smart textile. The project combines research on electronic packaging and interconnection technology with textile research to realize a variety of innovative applications using smart textile. It introduces new approaches for electronic packaging and module interconnects, making seamless and robust integration of electronics in textile possible. By leveraging the newly developed interconnect technology (mechanical crimping), the PASTA project has realized bare die integration into a yarn by means of micromachining (PASTA, 2016). In addition, the project develops a stretchable interposer serving as a stress relief interface between the rigid component and the elastic fabric. In this way, the proposed solution for textile-electronics integration is able to cover a wide range of components, from ultra-small off-the-shelf components, distributed sensors, to complex multichip modules (PASTA, 2016). The underlying concept relies on the development of hybrid integration approach interconnecting conductive yarns or functional fibers with crimp flat electronic packages. The developed textile-electronics integration approach can be applied in many textile-enable & patient-specific personal healthcare applications. One example can be found is a textile sensor developed from PASTA project, which is capable of continuously measuring stress and strain under the liability of daily life. The textile sensor has been applied into customized leg prosthesis for proof-of-function purpose, where the implemented textile sensor is responsible to measure global and local stress or strain along the full length of surface of the composite between the user's leg and the prosthesis. As reported in PASTA (2014), the developed textile sensor is not only applicable for prostheses, but in any smart textile based system where stress or strain needs to be monitored in composites.

Due to its favorable features, smart textile is taken as a promising alternative to the design of wearable healthcare systems, as it has the advantage of high wearability and addresses quite a lot on the user comfort issues. However, several common issues have been identified by the study of smart-textile based systems, which

constitute a set of challenges that will need to be addressed by further researches in order to make improvements from all aspects. These challenges include further miniaturization on sensor or system level, the improvement on reliability from both electrical and mechanical aspects, security issues of private information, clinical validation and standardization etc.

A Desirable Wearable Healthcare System

Wearable sensing devices will serve as the indispensable part of the future healthcare system, since they can continuously monitor users' health status, considerably improve users' life quality, and sometimes save their lives (Dey & Estrin, 2011; Mulder et al., 2009). A desirable wearable sensor device for personalized healthcare should be efficient, capable of detecting different bio-signals while also able to establish a wired or wireless network for multi biological parameters extraction. It is ideally free of cumbersome cables, and should be small in size, light in weight to address user comfort requirement. The ideal wearables should include the following features:

- Ultra-thin and light to make the device unobtrusive;
- Soft and flexible to fit to body curve;
- Ultra-low power consumption to achieve long battery life;
- Easy to apply; and
- Versatile sensing functions.

An example of desired wearable bio-sensing system which can be used for continuous personalized healthcare monitoring is illustrated in Figure 1 with an application scenario of a multi-channel ECG measurement. Intelligent Electrode is formed by embedding a System-on-Chip (SoC) in each electrode, which endows the electrode with local intelligence. In addition, by leveraging printed electronics technology, the whole sensing unit is implemented on a flexible substrate. As a result, user comfort issues are addressed when applying the implemented wearable devices on human body. The block diagram of the bio-sensing SoC is shown in Figure 2. With the integrated microchip, the Intelligent Electrode is able to obtain high quality bio-signal by conducting the bio-signal amplification, filtering, quantization, buffering, and transmission tasks directly on-site each electrode.

In this work the bio-signal acquisition and transmission tasks are distributed onto each electrode (distributed process). A body wired network is established by sharing a serial communication link (Active Cable); Intelligent Electrodes can communicate with each other in a serial manner. Intelligent Electrodes detect the bio-signals on specific sites of human body. These bio-signals are converted to digital format and gathered in one Intelligent Electrode, then the collected data is wire-

Figure 1. A wearable monitoring system based on flexible smart sensors connected via an active cable

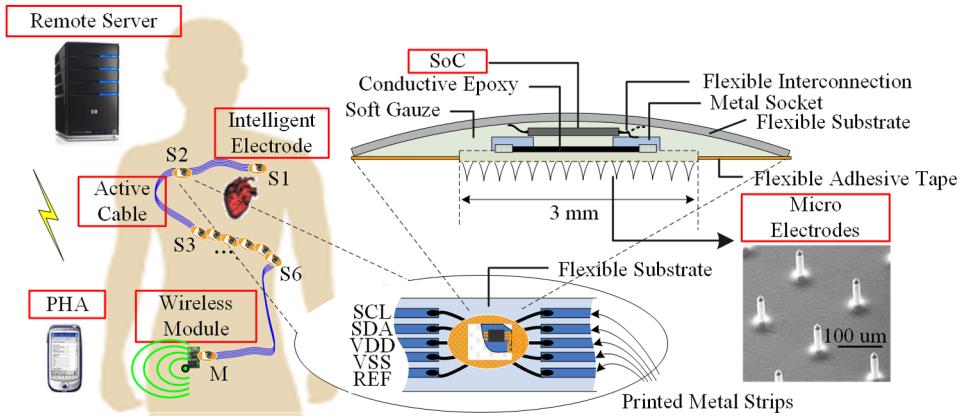
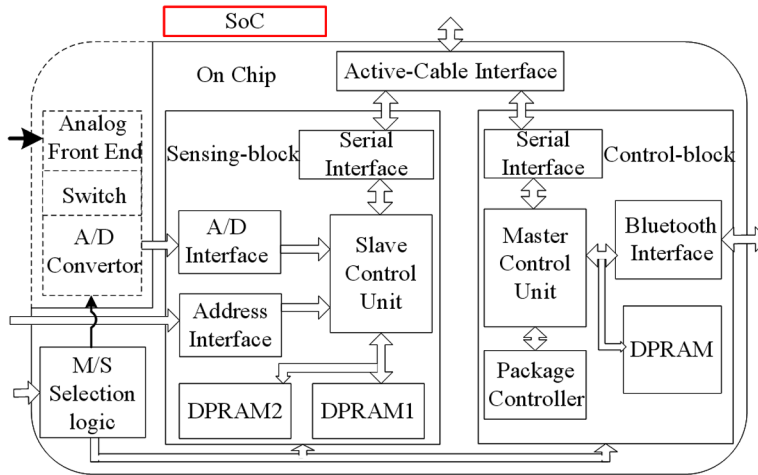


Figure 2. Block diagram of bio-sensing SoC



lessly transmitted to the Cloud via a smart phone or personal health assistant (PHA) for further processing and analysis. The concept of Intelligent Electrode and Active Cable are firstly reported in the attached (Yang et al., 2009).

The advantages of this presented wearable healthcare system include:

- One-chip multi-sensor. The customized microchip is designed with capability to sense a variety of bio-signals, which allows one Intelligent Electrode for multiple bio-signals sensing;

Hybrid Integration Technology for Wearable Sensor Systems

- Largely reduce the number of connecting cables. All sensing electrodes are connected by sharing a single Active Cable. As a result, user comfort can be improved;
- On-chip implemented serial communication protocol enables the establishment of a body area network over a group of Intelligent Electrodes; and,
- Non-invasive and unobtrusive Intelligent Electrodes are implemented by using inkjet printing technology and hybrid integration technologies, which makes the implemented sensor thin and flexible enabling further improvement on users' comfort.

To realize such a system, mainly two core research challenges are present: 1/ ultra low-power and high-performance integrated circuits design which is the key for sensing unit miniaturization; 2/heterogeneous integration of silicon-based rigid integrated circuits (IC) with printing-process based flexible electronics, which is the enabling technology to make the implemented sensor flexible and bendable.

The following part of this chapter is organized as follows. Firstly, a customized bio-sensing IC will be introduced. The designed IC can detect and process a selected type of bio-electrical signal emitting from human body, including Electrocardiogram (ECG), Electromyogram (EMG), Electrooculogram (EOG), and Electroencephalogram (EEG). Moreover, the feasibility of using highly accurate inkjet printing technology as enabling technology has been examined for the design and fabrication of flexible bio-sensing devices. Performance evaluation has been made to verify the electrical and mechanical reliability of the printed electrodes, and circuitry. The implementation of a flexible and wearable device by heterogeneous integration of silicon based bio-sensing IC with printed electronics will be explored. A wearable Bio-Patch has been implemented on flexible substrate by leveraging hybrid integration of printed electronics and silicon based bio-sensing IC. *In-vivo* test results show that the implemented flexible Bio-Patch provides high quality ECG signal which is comparable with the one gained by bedside ECG machine.

An implemented wearable sensor prototype will be demonstrated in this chapter, which are implemented by heterogeneous integration of the silicon based SoC and cost-effective printed electronics. The measurement results indicate the SoC operates smoothly with the printed electronics. The fully-integrated wearable device consisting of ultra-low power compact IC technology and printed electronics provides a promising solution for future personalized and pervasive healthcare applications.

CUSTOMIZED INTEGRATED CIRCUITS FOR WEARABLE SENSORS

An ideal wearable sensor should be miniaturized, unobtrusive, and long lasting. As the heart of the wearable sensors, a fully integrated low-power silicon-based SoC has been designed and implemented. By using high-level integrated SoC technology, a compact chip is achieved, which is a single-chip multi-sensor solution and is the key issue to realize bio-sensing electronic system miniaturization. The chip is a compact ultra-low power mixed-signal SoC, which is capable of concurrent measurements of multiple vital bio-signals (Yang, Wan & Zheng, 2011; Wan, Yang, Chen & Zheng, 2011).

State of the Art of SoC Technology

Silicon based SoC technology is playing an important enabling role in the advanced medical and healthcare systems: it serves as the core element of the sensing devices, and makes the devices smarter. Fully integrated design has shown great advantages in many advanced medical applications, in terms of low-power consumption, high-level integration and compact size (Lee et al., 2011; Vidojkovic et al., 2011; Salam, Sawan & Dang, 2011; Wattanapanitch & Sarpeshkar, 2011). Comparing with its counterparts, the off-the-shelf components based solutions; the SoC based solution is capable of integrating more complex circuit blocks with much lower power consumption in a smaller circuit area.

Due to the high integration capability and compact size, a SoC based solution enables the further miniaturization of sensing devices, and drives wearable sensor systems less obtrusive and more autonomous. In the past decade, considerable efforts have been made on developing advanced biomedical SoC and systems to enable physiological monitoring in novel application scenarios such as personalized healthcare applications. Due to the fact that these developed biomedical SoC are usually battery-operated or even wirelessly powered, great emphasis has been paid on ultra-low power design, enabling the sensing circuits to operate for days or even months using a small battery or even powered by wireless energy scavenger. In addition, since most of the sensing devices or smart sensors need to have direct skin contact for relatively long time, more emphases has been put on sensor miniaturization. The final goal with such miniaturization is that by making the sensing circuit as small as possible, the resulting sensor should be unobtrusive and easy to be attached on the human body or hidden into a wearable system. Examples can be found in battery-powered wearable or implantable medical devices: the bio-amplifier presented in (Burke & Gleeson, 2000; Zhaang, Qin & Hong, 2009; Liu & Tang, 2011; Xu, Zou, Yao, & Lian, 2008) can sense ECG activity; the ASIC reported in

Massagram et al (2010) can detect heart-rate variation; the implantable system in senses the EMG signal for intelligent prostheses control (Farnsworth, Taylor, Triolo & Young, 2009); acquisition of EEG is performed in (Yazicioglu, Merken, Puers & Van Hoof, 2007; Verma et al., 2010; Mohen, Kartikeya, Gert & Nitish, 2008; Fung, Liu, Yuan & Guo, 2009); neural recording and neural tissue stimulator are presented in Mollazedah, Muari, Cuawenberghs, and Thakor (2009), Harrison and Charles (2003), Shahrohki et al (2010), Gosselin, Sawan and Kerherve (2010), Miranda et al (2010), Lee et al (2010), Moosung et al (2008), Horiuchi, Swindell, Sander, and Abshier (2000) and Wattanapanitch, Fee, and Sarpeshkar (2000). Meanwhile, many world-leading research institutes, and biomedical industries have actively engaged in the development of customized SoC for biological sensing and bio-signals processing, like Sensium by Toumaz (2016). The absence of connecting metal wires, the look and user-feel of these bandage-like devices helps Sensium gain better user acceptance than traditional Holter-type monitors. Some other types of SoC based medical or healthcare devices have been developed and successfully undergone clinical trials. However, there are still existing challenges hindering a wider use of these SoC-enabled systems.

Most of the healthcare wearables have so far been limited to the acquisition of a single specific bio-signal, such as cardiac bio-potential or skin temperature etc.; other complementary and useful sensing modalities are missing. In most of the foreseen clinical scenarios, personalized healthcare monitoring will look for devices that can do more, such as multi-sensorial or multi-parameter measurement. In the following parts of this section, an implemented multi-inputs and multi-mode SoC sensor will be introduced. The demonstrated SoC based sensor is capable of establishing a self-configured wearable network and capturing multiple biological signals through configurable sensing ports to meet the requirements imposed by personalized health monitoring.

Bio-Sensing SoC Architecture and Implementation

The implemented bio-sensing SoC is a mixed-signal microchip. From the functional perspective, the designed SoC can be divided into 3 parts:

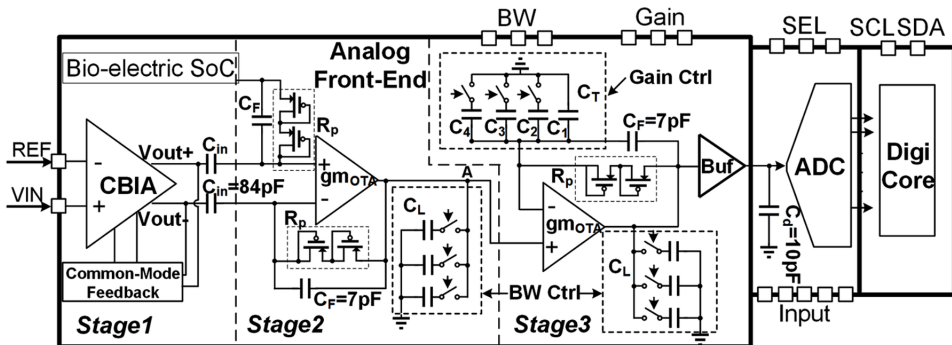
1. A bioelectrical analog front end (AFE), which is used to pick up and process the weak bio-signal from human body;
2. A successive approximation register analog to digital converter (SAR ADC), which is implemented on chip to convert the analog signal to a digital format; and
3. A reconfigurable digital core, which is the controlling unit responsible for a single wearable sensor management as well as the body network management.

The overall architecture of the bio-sensing SoC is illustrated in Figure 3. The front-end circuit with gain and bandwidth adjustment is quite useful in multi-parameter recording systems, which enables the SoC to process a variety of bio-potential signals, including ECG, EMG, EOG and EEG. The amplified bio-signal is converted to digital stream by the on-chip ADC, and stored in the on-chip RAM of the digital core (Mollazadeh, Murari, Cauwenberghs, & Thakor, 2009; Harrison & Charles, 2003; Shahrokhi et al, 2010; Gosselin, Sawan & Kerherve, 2010; Miranda et al, 2010; Lee et al, 2010; Chae et al, 2008; Horiuchi, Swindell, Sander & Abshier, 2004; Wattanapanitch, Fee and Sarpeshkar, 2000; Toumaz, 2016; Yang, Mao, & Zheng, 2010, 2009).

Bio-potential signals exhibit weak amplitudes and low frequencies. These weak signals tend to be submerged in the environmental noises or interference by other noises such as motion artifacts. The nature of bio-potential signals brings considerable challenges to the bio-signal read-out circuit. A desirable analog front end processing circuit should be equipped with programmable gain and bandwidth; thus it can be configured to accommodate different bio-potential signals (Yang, Chen, & Zheng, 2009; Yang, Chen, Cao, & Zheng, 2008). The circuit is also required to fulfill the stringent needs for the bio-signal detection: high input impedance, ultra-low power and low input-referred noise. The circuit should be able to pick up these weak signals from a noisy environment: amplify the target signal but effectively reject the unwanted noise (Hu et al, 2014).

A programmable three-stage AFE is implemented in this design. The block diagram of the AFE is illustrated in Figure 3. Stage1 is mainly composed of a current balanced instrumentation amplifier and a common mode feedback circuit. The differential outputs of Stage1 are AC-coupled to Stage2. Stage3 provides a tunable gain by tuning the equivalent capacitance of its inner capacitor bank via three

Figure 3. Overall architecture of the bio-sensing SoC



external switches. The in-band gain of the Stage3 can be configured to 8 different values ranging from 2 to 19.

According to simulation results, the three-stage front-end circuit can totally provide a tunable close-loop gain ranging from 45 dB to 64 dB. The low-pass frequency of the front-end can be tuned to 80 Hz, 260 Hz, 400 Hz or 1 kHz by varying the on-chip load capacitance through the external switches. The three-stage gain-bandwidth tunable architecture allows the adjustment of the gain of the amplification chain to an optimum value, while avoiding saturation distortion. The AFE totally draws a current of 2.3 μ A from a 1.2 V supply. Detailed schematics for each stage and the corresponding theory analysis can be found in Ynag et al (2012).

The bio-sensing SoC is fabricated in a standard 0.18- μ m Mixed-Mode 1P6M CMOS process and totally occupies 1.5 mm $\times$ 3 mm silicon area with an adaptive operating voltage ranging from 1.2 V to 3.3 V. Since the high density integrated circuits is identified as the key enabling technology for device miniaturization, all indispensable processing circuits blocks, including digital controlling logic and analog circuits, are compactly implemented in a tiny area of 4.5 square millimeters. Figure 4 illustrates the implemented silicon based bio-sensing SoC (without chip package) on a finger for scale, which gives an intuitive vision on how far the wearable device miniaturization can reach. A chip microphotograph with all building blocks marked is shown in Figure 5.

Figure 4. Bio-sensing SoC on a finger

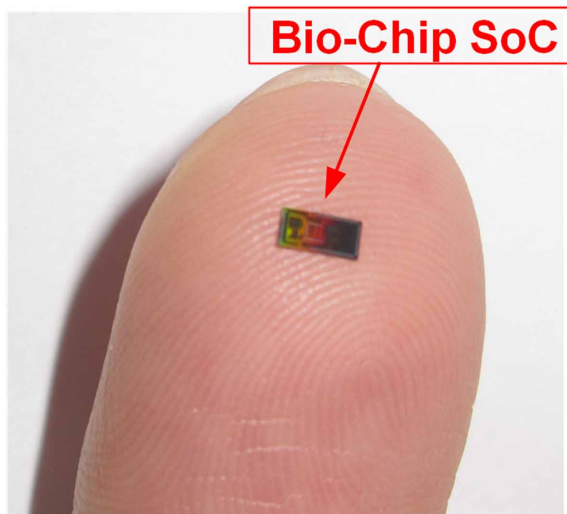
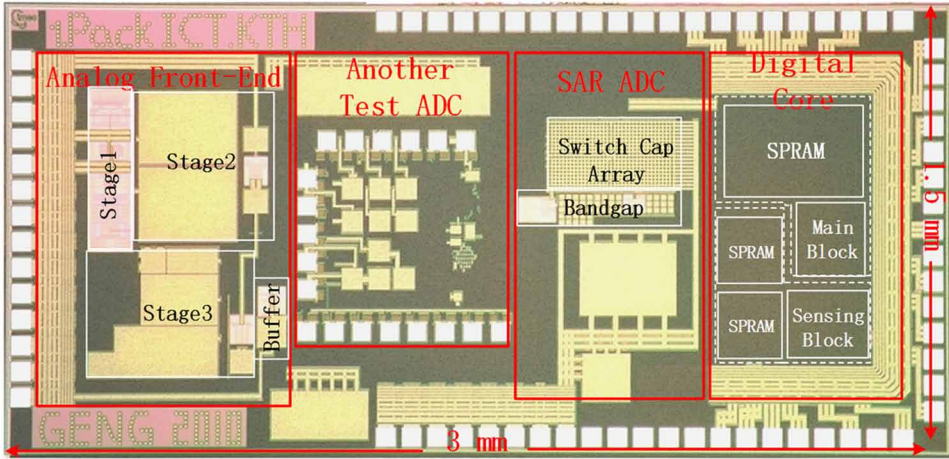


Figure 5. Chip microphotograph with its building blocks marked



Analog Front End

In order to measure different bio-signals, gain and bandwidth are designed to be tunable on AFE, as shown in Figure 6. To make an intuitive comparison, AFE circuits simulation result and chip measurement results are given in Figure 6. The AFE gain-bandwidth measurement result from a fabricated SoC is plotted in Figure 6, and gain-bandwidth post layout simulation result is plotted in Figure 7. The measured and simulated gain and frequency response of the AFE are quite in line with each other with small exception of measured gain slightly smaller than simulation result. For example, the maximum gain measured is 63 dB which is 1 dB smaller than the simulated value. One possible reason is the attenuation caused by the unit buffer which is connected to the end of AFE amplifier chain with the function to increase the AFE driving capability. The attenuation of the unit causes the slightly less measured gain. Both the gain and bandwidth can be independently configured via external pins. 8 different gains with range from 45 dB to 63 dB can be selected (three of them are illustrated in Figure 6 and Figure 7). For each gain setup, four 3-dB bandwidths can be obtained by programming of bandwidth switches. The upper part of Figure 6 shows the case of 3-dB bandwidth adjustment with 0.3 Hz low cut-off frequency and adjustable high cut-off frequency ranging from 85 Hz to 850 Hz at an almost consistent gain of 62dB.

Table 1 summarizes the amplitude and frequency characteristics of a specific bio-potential signal, and the bio-sensing SoC is configured accordingly via external switches for the specific measurement.

Figure 6. AFE Gain-bandwidth measurement result

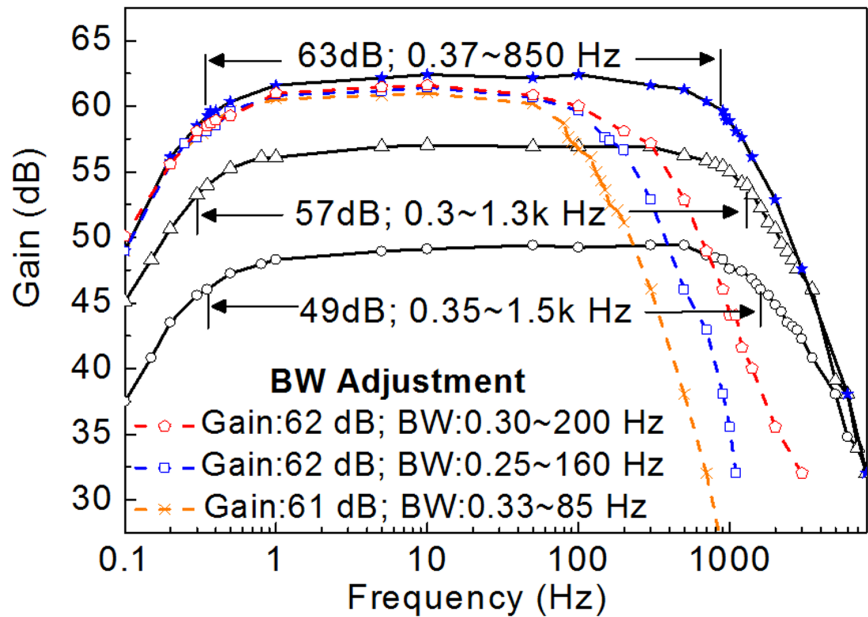


Figure 7. AFE Gain-bandwidth simulation result

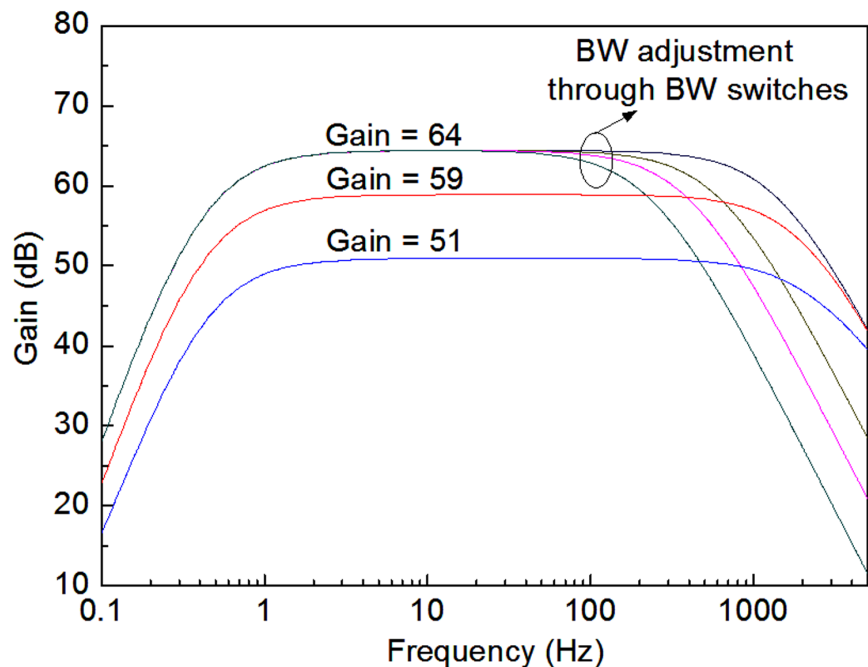


Table 1. Bio-sensing SoC setup for different recording applications

Bio-Signal	Gain Pin Set	BW Pin Set
	Gain of AFE	BW of AFE
ECG (0.5-150 Hz) (0.1-3 mV)	‘100’	‘000’
	49 dB	0.35 Hz-1.5 kHz
EMG (14-250 Hz) (0.01-2 mV)	‘010’	‘000’
	57 dB	17 hZ-1.5kHz
EOG (0-30 Hz) (0.1-1 mV)	‘010’	‘111’
	57 dB	.25 Hz-190Nz
EEG (0.5-40 Hz) (10 μ V - 0.1 mV)	‘111’	‘011’
	62 dB	0.37 Hz-850 Hz

Digital Core

The goal of intelligent wearable devices design is to support and simplify our daily life through embedding smart electronics and flexible sensors into clothes or skin-attached devices. These smart wearables sense their environments, process information, and communicate by wireless links. Electronics as basic elements disappear or are cleverly hidden, but their functionalities are available in a ubiquitous fashion.

In this design, the Digital Core serves as the controlling logic and is responsible for digital bio-signal collection, buffering and streaming out. In addition, the Digital Core also takes charge of communication between sensor nodes and the management of body area network. A 2-wire serial transmission protocol is on-chip implemented. According to specific requirement, broadcast commands or unicast commands can be issued to communicate with other sensing nodes attached on the body. With this protocol, a body area network can be established and managed.

A typical body area network requires at least two types of sensor nodes: one is responsible for sensing specific bio-signals from human body, and the other type operates as a controller to manage the whole network. In this work, the two operating modes are combined and implemented on the same chip.

The chip can be configured either to a Sensing Node (SN) or the Main Node (MN). The difference between the two operating modes exists in:

- **SN Mode:** The main function of a SN is to sample, process and buffer the bio-signal. Each SN has a 4-bit address. The bio-signal from the subject's skin is amplified and digitized. Subsequently, the digital bio-signal is picked up and buffered temporarily in SN's on-chip RAM. If one RAM is full, the

- upcoming data are automatically switched to the second RAM. Before the on chip memory is full, the stored data will be periodically collected by the MN;
- **MN Mode:** The main role of the MN is to manage the whole network using a variety of commands. SN-Chain Scan (SNCS) process is initiated when the system is powered up or reset. During SNCS process, all SNs in the chain are scanned; the address of each active SN is stored in the MN's address buffer. Soon after SNCS is completed, bio-signal data collection process is initiated: the MN visits each SN in a serial manner. Collected data are buffered in a MN's on-chip RAM. Before the storage is full, the MN forwards these data to the outside world via an external wireless transmission module, and then it continues with the next round of data collection.

The SNCS flow is described in Figure 8. The MN broadcasts a command packet containing a target SN address to the Active Cable. If the target SN is available on-line, it responds with an acknowledgement immediately. Otherwise, if the target SN does not exist, no acknowledgement will be generated before MN's timer overflow. Subsequently, the MN skips current SN, and continues with the next visit until all SNs are scanned. The current system supports 14 SNs and 1 MN. Figure 9 illustrates the command structure. Figure 10 shows the screenshot of SCL and SDA on an oscilloscope during SNCS. The 'start' and 'stop' commands for the implemented serial communication protocol are compatible with Philips I2C, while the definitions for the rest of commands, for instance, broadcast and unicast commands are custom-designed.

PRINTED ELECTRODES AND THEIR CHARACTERISTICS

Electrodes for bio-potential measurement are designed to record bio-electrical signals while reducing the potential picking up of artifact. Many practical considerations

Figure 8. Command-based SN-Chain Scan (SNCS) process

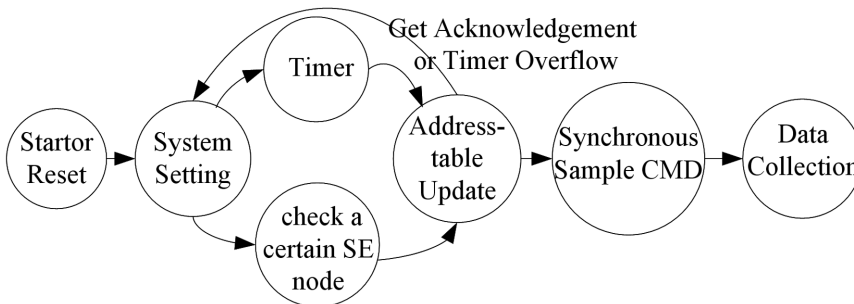


Figure 9. Packet structure for the command frame

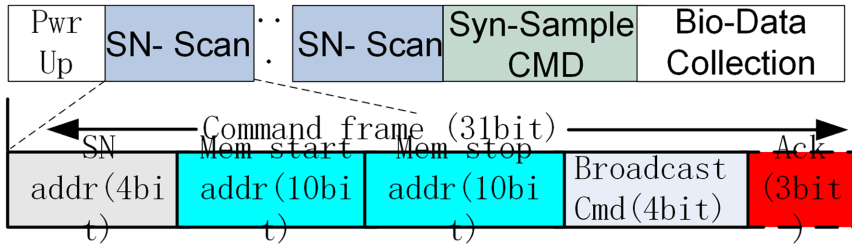
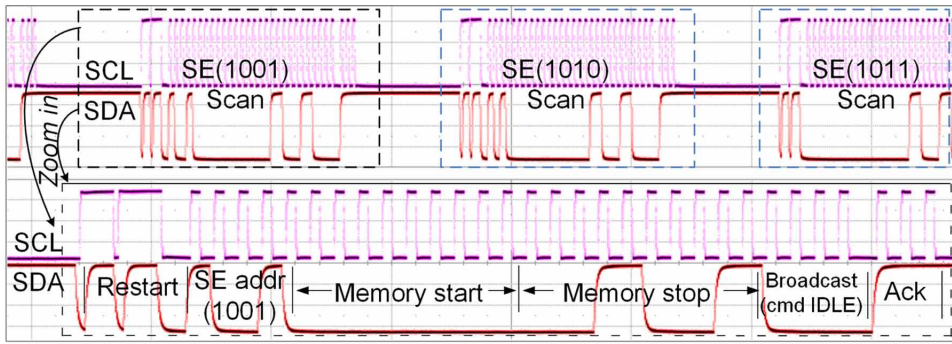


Figure 10. Oscilloscope screenshot of the SCL and SDA during SE-chain scan



suggest the electrode design should be pragmatic to address the capability of massive manufacturing and reliable long-term use. Also, requirements from specific application scenarios determine whether to choose high-quality reusable electrodes, or low-cost disposable electrodes (Xie, Ynag, Mantysalo, Jonsson & Zheng, 2012).

Electrode Technology

Most of bio-electrical signals acquisitions are made with the aid of electrodes which serve as the interface between human body and medical devices for the recording of a specific bio-electrical activity (Searle & Kirkup, 2000). The standard silver/silver chloride (Ag/AgCl) electrodes have been well-characterized and studied over many decades (Huigen, Peper & Grimbergen, 2002; Spach, Barr, Havstad & Long, 1966). With proper preparation and electrodes deployment, they can provide good signal quality at a relatively low cost. Depending on if conductive gel is applied, the contact electrodes can also be divided into wet electrodes (Griffith, Portnoy, Sotts & Day, 1979; Bouwstra, Feijs, Wei & Oetomo, 2009; Kato, Ueno, Kataoka, Hoshino & Ishiyama, 2006) and dry electrodes (Sullivan, Deiss, Jung & Cauwenberghs, 2008;

Merrit, Nagle, & Grant, 2009; Cho et al., n.d.). According to the degree of invasiveness, electrodes can be classified into different categories. Typically, they can be classified as invasive electrodes (which have to be surgically implanted into the human body, e.g. placed on the surface of the brain or implanted into muscle groups for stimulation) and non-invasive electrodes (usually skin-attached). Depending on if electronics is contained, the non-invasive electrodes can be further divided as: passive-electrode (without electronics), and active-electrode (with electronics). In this work, we focused on the non-invasive one, the surface-mounted electrodes, and propose the concept of Intelligent Electrode which is one type of active-electrode with local intelligence by embedding a SoC (Yang et al, 2012). Based on this concept, we further developed several prototypes of skin-friendly Bio-Patch by combining the technical advantages of the integrated circuits and printed electronics.

Active Electrode

In recent years, many attempts have been made to improve the traditional electrode technology. Several research groups are developing active electrode. The bio-signal amplification/buffering takes place locally inside the electrode. By doing so, an output signal with much better quality is expected. The relative usage of the active electrode, in contrast with the more widespread standard passive electrode, is usually tied to novel cardiac or neurological applications. Thomas Degen *et al.* presents a two-wired buffer electrode. Yu Mike Chi *et al.* developed a non-contact active electrode for ECG/EEG applications (Yang, Xie & Zheng, 2013; Sullivan, Deiss & Zauwenberghs, 2007; Chi & Cauwenberghs, 2009; Sullivan, Deiss, Tzzy-Ping & Cauwenberghs, 2008). Several attempts have been made to integrate active electrodes in chairs and beds (Yong Gyu, Keun & Suk, 2006; Yong Gyu, Keun, Kwang Suk, 2007) to obtain the user's cardiac signal.

Although active electrodes are featured with improved immunity against environmental interferences, they are not used as often as expected. Firstly, a survey of published works shows that active electrodes are almost exclusively designed using off-the-shelf components, such as operational amplifiers. The use of many off-the-shelf components leads to a cumbersome sensor size. Moreover, as the components carrier, the Printed Circuit Board (PCB) itself is stiff. As a result, the active electrode's wearability is low, and not suitable for long-term wearable devices. Secondly, extra wires (such as power supply and ground wires) are introduced in for each active electrode, which results in even more connecting cables comparing with the traditional methods. The resulting size and user comfort are the limiting factors when considering integrating more complex circuits into the active electrode using the off-the-shelf components.

Passive Electrode

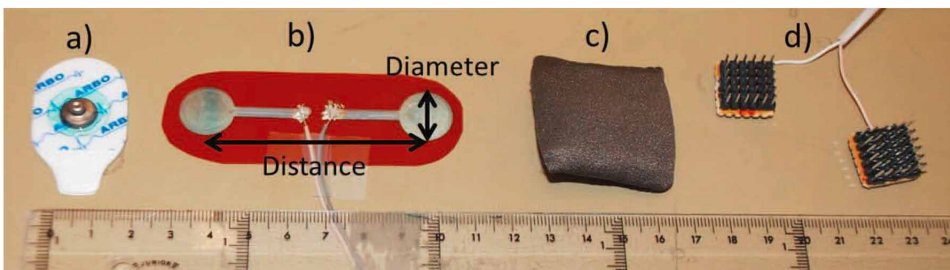
Electrodes form electric paths between human body and the sensing/stimulating circuits. Taking bio-electrical sensing as an example, electrodes are regarded as a class of sensors that transducer bio-potentials from human body to the read-out circuits where the signals can be detected and processed. The conventional adhesive passive Ag/AgCl electrodes commonly find their applications in clinical and research applications today. The standard Ag/AgCl electrodes have been well-characterized and studied over many decades. With proper preparation and electrodes deployment, they can provide relatively good signal quality at low cost. Figure 11 presents a sample of commercially available pre-gelled electrode (ARBO).

Moreover, depending on if conductive gel is applied when attaching the electrodes onto the human skin, the passive electrodes can be categorized as dry electrodes (without electrolytic gel) and wet electrodes (with electrolytic gel applied). Dry and wet electrodes have their own cons and pros. Take the monitoring of chronic disease as an example; conventional Ag/AgCl wet/pre-gelled electrodes have the potential risk of irritating the skin due to the long time attachment on a specific location on the skin (for instance, burn units or neonatal care). In addition, the signal quality and system performance degrade when the electrolyte gel dries out, and it is inconvenient to make skin pretreatment before the measurement taking place on hairy chest. Therefore, many attempts have been made to overcome the drawbacks of wet electrodes.

Dry Electrode

To address the challenges mentioned above, dry electrodes are proposed as alternatives to the wet electrodes. Depending on the nature of the carrier substrate, coating

Figure 11. Samples of different types of electrodes: a) commercial pre-gelled electrode b) a pair of inkjet printed electrodes on polyimide substrates, c) textile electrode, d) a pair of spiked electrodes



materials, and physical features, dry contact electrodes can be identified as conductive polymer/rubber electrodes, metal or carbon electrodes, needle/spike electrodes, and fabric-based electrodes etc. Due the unique feature of each type, dry electrodes can be selected as suitable solutions for a variety of medical or healthcare applications (Xie et al., 2013).

1. **Electrodes Based on Planar Metal Plate:** The media could be standard rigid PCB, flexible etched copper plate or flexible substrate such as polyimide and photo paper using printing technology. One example is presented in Figure 11b which is a pair of printed electrodes (PrinteE) implemented on polyimide substrate using conductive inks. By attaching the planar metal plate onto the skin, electrical path could be formed between the subjects under test and the medical devices. Isolated by dielectric layer, e.g. cloth, this kind of electrodes and the skin form parallel-plate capacitor and can be used for non-contact bio-signal measurement.
2. **Textile Electrodes (TextE):** The fabrication methods of TextE include: a) conductive yarns weaving, knitting or embroidering along with normal yarns, b) screen-printing conductive pastes on top of fabric. A TextE sample can be found in Figure 11c. The textile-based electrodes could increase the user comfort and be unobtrusively embedded in clothes such as t-shirts, and garment etc. Because TextE features lightweight, ductile, washable, resisting abrasion and moisture, it is suitable for long-term continuous monitoring.
3. **Spiked Electrodes (SpikE):** For certain application scenarios, bio-electrical signal extraction or stimulation cannot be simply conducted via traditional electrodes, such as ECG measurement through hairy chests, EEG measurement from the head with hairs, or bio-potential signal monitoring of animals. Unavoidably, wet electrodes encounter problems when applying them on the shaggy skin, since it leads to unstable skin-electrode attachment, which in return induces huge contact noise, and in most cases, results in measurement failure. One solution nowadays is skin pretreatment by shaving the hairs. The limitation of this approach is obvious, since it is inconvenient and time consuming, furthermore, patients may be unwilling to shave their hairs. For such application scenarios, SpikEs are quite useful, because the conductive spikes/needles can easily penetrate the hair and make contact with the skin to form the electrical connection. A pair of SpikEs is illustrated in Figure 11d.

According to the requirement from specific applications, e.g. brain-computer interface, stimulator array of an artificial limb, etc., the diameter of electrodes, the number of electrodes, physical characteristic of the electrode and its substrate (e.g.

flexibility and stretchability, etc.), and the spacial density, need to be fully considered during the design

and manufacturing of electrodes or electrode array. Some performance evaluation has been made on printed electrodes to further investigate its potential usage in the biomedical domain.

Several pairs of printed electrodes (PrintE) are implemented on the photo paper substrate. A pair of silver electrodes with an electrode distance of 12 cm is selected for test, as shown in Figure 12. The electrodes and connection traces are fabricated using inkjet-printing technology. Figure 13 shows the cross section view of the printed electrode. The sample was made by inkjet-printing nano-silver ink onto inkjettable photo paper and followed by oven-sintering. The paper substrate used is roughly 250 μm and sintered silver layer is around 25 μm . Inkjet-printing technology is selected due to the easy-prototyping. Various printing technology such as stencil printing or screen printing can also be used for high-volume production.

A bio-sensing SoC measurement board was employed to evaluate the performance of electrodes. The *in-vivo* test was applied by connecting the printed electrodes to

Figure 12. Printed electrodes with electrode distance of 12 cm on a photo paper substrate

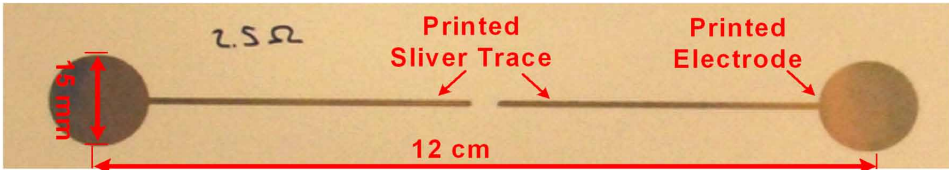
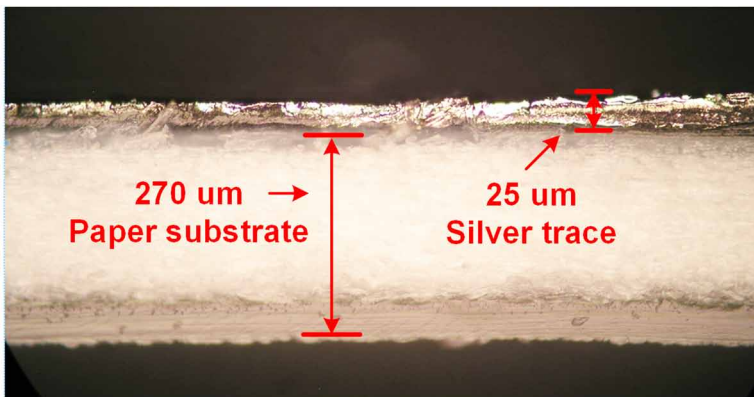


Figure 13. Cross section view of the printed electrode



the differential inputs of analog front-end (AFE) on SoC. A photo of the conducted *in-vivo* test is shown in Figure 14. For demonstration purposes, the oscilloscope was stopped with a captured ECG signal held on the screen, and the printed electrodes were intentionally held outward of the chest which should be facing towards chest in real test. An elastic bandage was used to hold electrodes to the skin, a clean ECG waveform (the output of SoC's AFE) can be observed on the oscilloscope shown in Figure 14.

In addition to the performance evaluation of PrintE, similar *in-vivo* tests are also applied to the other three types of dry electrodes, which are Commercial Electrodes (CommE), TextE, and SpikeE. The tests are conducted by connecting the selected dry electrodes with the same bio-sensing SoC measurement board. All tests are under the same circuit setting (gain and bandwidth) for ECG recording, as shown in Figure 14.

The performance of these dry electrodes are evaluated and compared in terms of contact impedance, induced noise and captured ECG signal through *in-vivo* tests. The ECG signals recorded by the four types of electrodes are shown in Figure 15 (raw signals only without any digital signal processing). ECG signal obtained from CommE is taken as a reference. The experimental results indicate that TextE and PrintE obtain similar quality of ECG signals comparing with CommE, while SpikeE induces large noise. However, the QRS complex is visible and the signal quality could be improved by backend signal processing. From the user comfort point of view, TextE is comfort when applied on the chest of a test subject, but it

Figure 14. ECG test with paper based printed electrodes connected with bio-sensing SoC

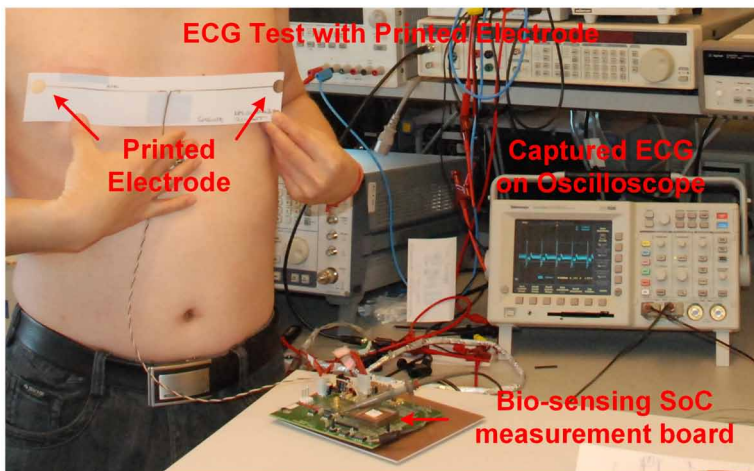
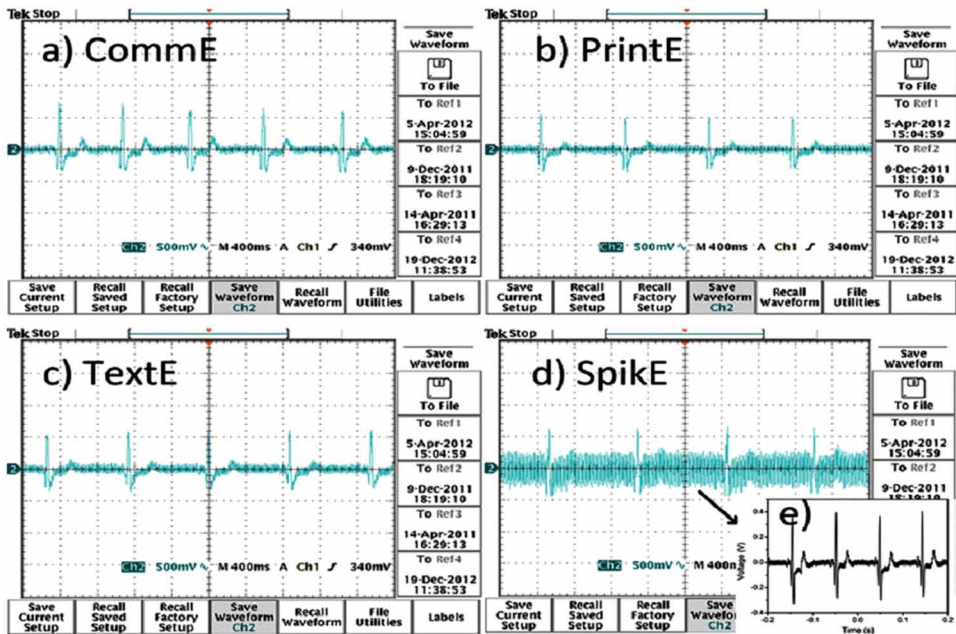


Figure 15. The oscilloscope screen shot of the ECG signal captured by a) CommE, b) PrintE, c) TextE, d) SpikeE, and e) filtered ECG signal of d)



is sensitive to motion and pressure due to the comparatively unstable mechanical and electrical contact with the skin, which brings in more challenges for back end digital bio-signal processing.

Each type of bio-potential electrodes has its own distinct features. The selection of a specific type of electrode is up to application requirements. When it comes to the implementation of a user friendly wearable device, PrintE is selected for hybrid integration, because it has advantages fitting with project requirements as follows:

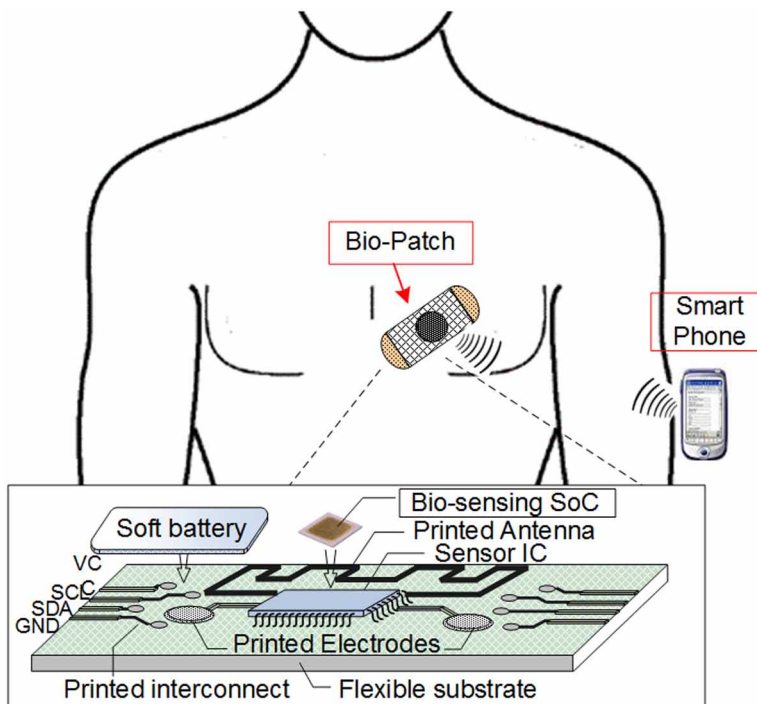
1. It has stable performance which is comparable with CommE;
2. It is thin, flexible and lightweight which can attach well to the human body with respect to skin convexity;
3. Its manufacturing process is compatible with digital hybrid integration process.

In addition, the inkjet printing technique makes it easy to customize the electrode pattern. In the following section of this chapter, a flexible wearable sensor will be introduced which is implemented by hybrid integration of printed electrodes and silicon based bio-sensing SoC.

HYBRID INTEGRATION OF FLEXIBLE WEARABLE SENSORS

A desirable wearable sensing device for personalized and pervasive e-health should be efficient, capable of multiple vital bio-signals sensing while the user comfort and user experience are the issues that must be addressed (Yang et al, 2013; Shen et al., 2015; Anurag et al., 2014; Hiremath, Yang & Mankodiyda, 2014; Abtahi et al, 2014). The work is aiming to create an unobtrusive sensing system for personalized health monitoring and treatment. It is ideally free of cumbersome cables, and should be small in size, light in weight, low power, low cost and disposable after use. A bandage like wearable sensor could be a good example for unobtrusive sensing. It is soft and flexible, can be unobtrusively attached to user's skin and automatically collect user's health information (Ji, Yang, KJang, & Zheng, 2015; Ji, Ouyang, Yang & Yang, 2015; Kanth et al, 2014; Hamed, Tenhunen & Yang, 2015). Advances in microelectronics, nano-materials, sensor technology, integration technology, and information and communication technologies have made possible the implementation of a soft and flexible sensing device to realize the concept of “wear and forget” (Yang, et al, 2013).

Figure 16. The concept of Bio-Patch for wearable personalized health monitoring system



The concept of the proposed Bio-Patch is illustrated in Figure 12. It integrates the bio-sensing SoC, a pair of printed electrodes and interconnections, and a soft battery on a flexible substrate. It can be directly attached on human skin to collect a specific bioelectric signal (in this section, ECG recording is taken for a straight forward demonstration). With the SoC sensor embedded inside, the Bio-Patch is featured with high quality bio-signal extraction by conducting the bio-signal amplification, filtering, quantization, buffering, and transmission tasks directly on-site each patch.

Flexible Circuits and Interconnections

Inkjet printing technology is employed in this design as the enabling approach to print conductive electrodes, passive components, circuit board, and integration interconnections. The advantages of using the inkjet printing technology to implement the proposed Bio-Patch include (Xie et al, 2015):

- A green technology for electronics assembly. Compared with conventional PCB manufacturing, inkjet printing tech is more environmental friendly, since it does not involve masks or etching steps, thus avoids the use of harsh chemicals. It is print-on-demand, avoiding material waste. Therefore, with this technology, it is more convenient to apply customized bio-sensing elements/patterns according to a specific requirement;
- Time efficient with less process steps. Inkjet printing tech supports roll-to-roll massive production. The conductive electrodes and all the interconnections can be made at the same time on the same substrate; and,
- Devices miniaturization and steps towards new packaging technology. Inkjet-printing of nano-metal particles can be used to connect chips to package (e.g. System-in-Package) or directly print circuits on boards (e.g. Chip-on-Board). More compact patch/sensor can be achieved due to the thin profile of printed electrodes/interconnections. The smaller/more unobtrusive the patch/sensor is, the more unobtrusive and comfortable for the user to use.

In this work, digital inkjet printing technology is employed to fabricate the printed electrodes and electrical interconnections on the patch. The digital inkjet deposition is a contact-free manufacturing technology, which does not involve any complicated process, so passive components can be easily made at relatively low cost. A Dimatix DMP inkjet printer is used to deposit small droplets (10 pl for each droplet) of silver nano-particle ink (NPS-JL) directly and accurately on the polyimide substrate to form electrodes and circuit interconnections. The processing resolution is set to 1270 dpi with the drop spacing of 20 μm (center to center).

The printed structure is sintered by heat in an oven, so that the solvents and other additives are effectively removed by thermal decomposition and evaporation, and at the meanwhile the nano-particles join together to form a continuous and uniform structure that enables formation of metal clusters/plate.

Silicon-on-Flex

By leveraging compact SoC technology, miniaturization of wearable sensing device can be achieved by packing all the indispensable electronic modules onto the same chip, which leads to the minimum need of peripheral electronic components to fulfill the functional requirement. However, the chip packaging, as the container of the silicon chip, usually takes a much larger space than the silicon die itself. In this work, we explore the potential to miniaturize the physical dimension of Bio-Patch: instead of using a standard-packaged SoC chip, investigations are made to directly integrate a bare silicon die onto flexible substrates, named Silicon-on-Flex.

This brings in great challenges to the integration technology and the following limitations must be overcome:

1. The dimension of the pad on the silicon is quite tiny, as small as $65\text{ }\mu\text{m} \times 65\text{ }\mu\text{m}$, with a pitch of $90\text{ }\mu\text{m}$. The dimensional limitation directly influences the yield of printing the electrical connections with sufficiently low resistance. During the integration process, adjacent pads can easily get short-circuited with each other;
2. The nature of flexible substrate is soft which brings high reliability requirement of the interconnections and the system.

Moreover, it cannot stand very high temperatures and high mechanical puncture or pressure. As a result, traditional integration methods, such as wire bonding and solder balls, are not applicable in this case. Owing to the features of high accuracy and fine resolution, inkjet printing technology can not only be used to manufacture electrodes and circuit boards, but also be used as an integration approach. Therefore, the whole pattern could be printed at once, including the electrodes, the circuit board, and the interconnections connecting the pads on the die with the circuits on the flexible foil. It is worth mentioning that, by merging the steps of printing the circuit and electrodes into a single step, the whole manufacturing process for a device is further simplified.

To verify the silicon-on-flex concept and to optimize the printing setup, a test silicon chip with the pad size of $90\text{ }\mu\text{m}$ is employed. Figure 17 shows the inkjet printed electrical paths created between the pads on the silicon and traces on the substrate: top view (Figure 17a) and side view (Figure 17b). Owing to the merits

of inkjet printing technology, such as accurate alignment and fine resolution, parallel lines are successfully printed with a well-controlled line width. The lines form conductive interconnects from the bumps on chip to the flexible substrate.

Bio-Patch Implementation and Miniaturization

Figure 18 shows the microphotograph of a Bio-Patch prototype based on the hybrid Silicon-on-Flex integration. The width of inkjet-printed interconnects can be as thin as 50 μm . Totally 14 parallel interconnects have been successfully printed within a narrow space of 1.5 mm (one edge of a bare die) without any open-circuit or short-circuit.

By integrating the customized bio-sensing SoC, a pair of optimized electrodes, and a few peripheral passive components, miniaturized Bio-Patch prototype was implemented on polyimide substrate for single-channel ECG measurement. The prototype photo is illustrated in Figure 19 (Xie et al, 2012). Including the electrodes and the coin battery assembled on the backside, the total size of the Bio-Patch is 4.5 cm $\times$ 2.5 cm with a thickness of 2 mm. The thickness could be further reduced to 1 mm if a soft battery (e.g., an Enfucell printed battery) is used. By integrating electrodes on the Bio-Patch as a whole, users or caregivers do not need to snap the electrodes one by one every time, thus save maintenance or operation time.

The hybrid integration approach of Silicon-on-Flex makes the developed Bio-Patch small, ultra-thin, and bendable. With the help of bio-compatible adhesive tape, the implemented Bio-Patch can be easily attached on to the user's chest. Due to the use of thin flexible polyimide substrate, it works like a 'Band Aid'. The implemented Bio-Patch aims to gain better user acceptance by significantly improving user's comfort by addressing the "wear&forget" concept (Yang et al, 2013). As the

Figure 17. An example of inkjet printed interconnects for bare die integration from a) top view, b) side view

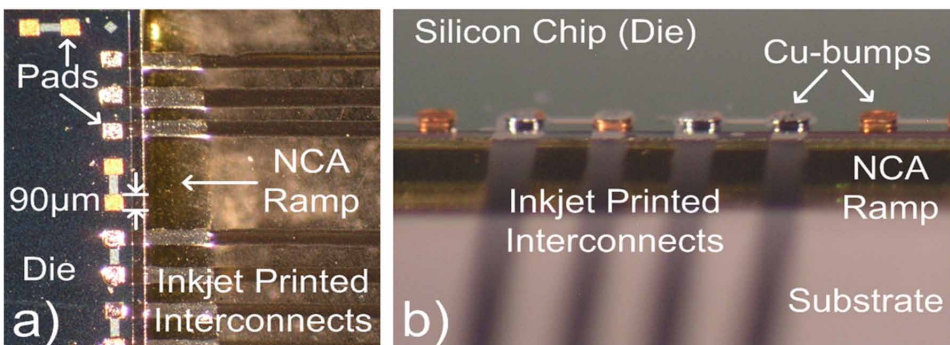


Figure 18. Hybrid integration of Bio-Patch using inkjet printing technology

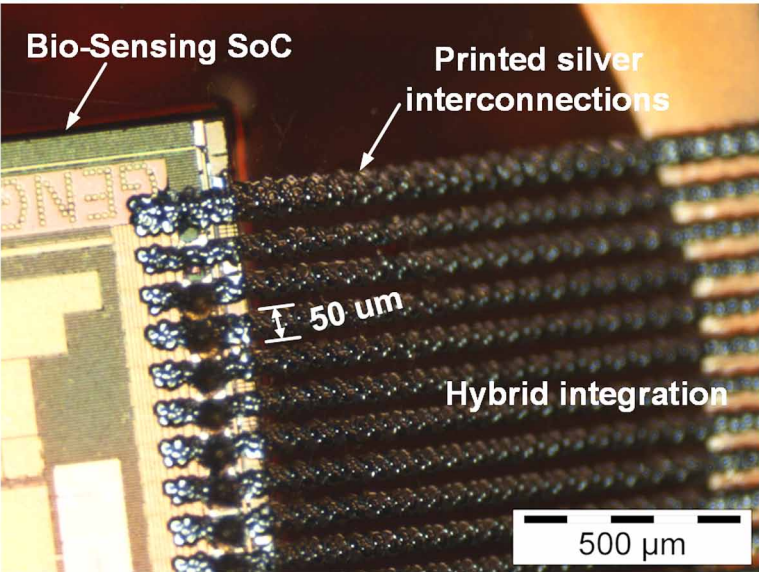
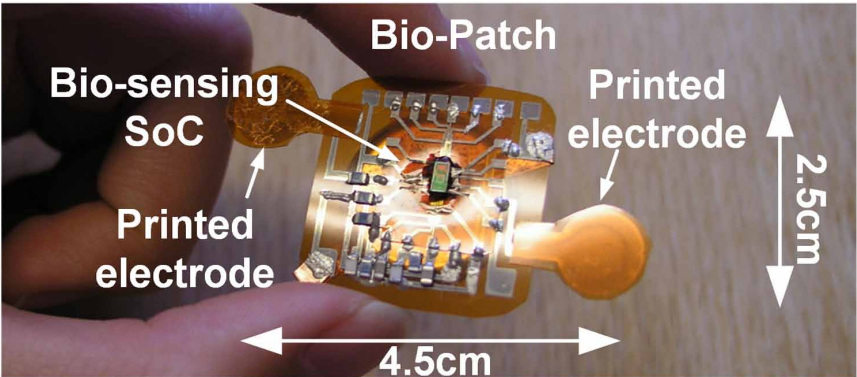


Figure 19. Miniaturized Bio-Patch for single-channel ECG measurement



key enabling technology, the silicon-on-flex hybrid integration technology is identified as one of the feasible solutions for wearable devices fabrication. The ECG signal captured by the Bio-Patch is shown in Figure 20. Influenced by 50 Hz power-line interference, a slight noise can be observed from the measured ECG signal (raw signal only), even without backend digital signal processing, the key features of ECG, including the PQRST complex, are clearly visible. The performance of the implemented Bio-Patch is summarized in Table 2.

Figure 20. ECG signal captured using the implemented Bio-Patch

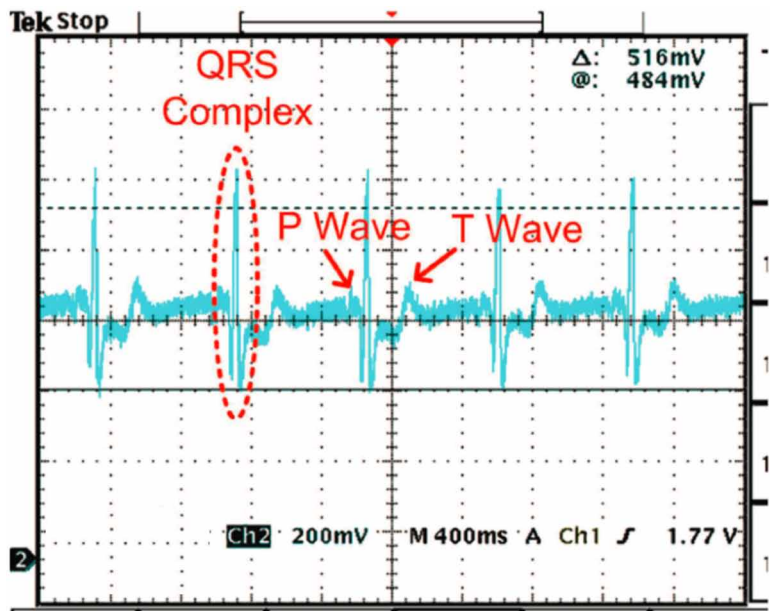


Table 2. Performance summary

Parameter	This Work
SoC Process	UMC 0.18 μm 1P6M CMOS
Silicon area	1.5 mm x 3 mm
Supply voltage	1.2 V ~ 3.3 V
Patch size	4.5 cm x 2.5 cm
Conductive link	NPS-JL from Harima
Substrate	Polyimide
Electrode	Printed silver electrode
Front-end power	2.3 μA @1.2 V
ADC power	1.8 μA @1.2 V

DISCUSSION AND CONCLUSION

In this work, the performance of printed electrodes and interconnections on flexible substrates has been studied. Inkjet printing technology has been employed to print these patterns. By connecting the printed electrodes to the bio-sensing SoC, high quality ECG signal has been successfully recorded. Experiment results show that

the printed electrodes are compatible with the implemented SoC. Inkjet printing technology is identified as one feasible approach to integrate customized electrodes and other patterned electronics with silicon based IC on flexible substrates such as photo paper or polyimide substrate. Wearable device miniaturization and system integration using inkjet printing technology on flexible substrates has been further investigated. The hybrid integration concept of silicon-on-flex has been demonstrated through the implementation of a wearable device by combining a compact SoC with printed electronics. A proof-of-concept Bio-Patch prototype has been implemented on the polyimide substrate. Preliminary experiment results have shown that ECG signals are successfully measured through *in-vivo* tests.

The aim of this work is not limited to evaluating the performance of printed interconnects or comparing the characteristics of printed components with the commercial ones, but addressing the user comfort issues by combining the “wear&forget” concept into the implementation of a wearable bio-sensing device. A workable Bio-Patch prototype has been successfully implemented by utilizing the digital inkjet printing technology to integrate the customized SoC on a flexible substrate. The developed patch gets rid of cumbersome connecting wires and avoids complicated electrodes configuration/placement, therefore, maximizing user comfort. Preliminary measurement results show that ECG signals are successfully measured when applied on the subject’s chest. The implemented skin-attached Bio-Patch enables unobtrusive sensing in our daily life. Combined with the large health data collection and proper big data analysis of physiological change of an individual over time, the proposed wearable system provides a promising solution for personalized health monitoring and treatment.

Considering the implemented wearable patch in the design for continuous long term health monitoring, several practical issues should be taken into consideration for further improvements of the device from the aspects of users’ comfortableness and device’s performance reliability. As reported earlier in this chapter, the core electronic module, the bio-sensing SoC, has been designed to be ultra-low power consumption (tens of micro-Watt level), however, if the power consumption of a wireless data transmission module is counted in (tens of mili-Watt level in general), the continuous running of the system will cause heat dissipation problem. In order to solve the potential problem, the following two approaches have been identified. One is to improve the device’s heat dissipation capability by implementing arrays of tiny holes at the spare area of the patch’s substrate. With the help of the tiny holes, the skin part covered by the patch can be exposed to the external air, leading to a breathable substrate, as a result, heat and sweat can be efficiently dissipated. Since the wireless module is known as a power hungry module for a wearable device, another approach which can mitigate the patch’s heat problem is to leverage the re-scheme of wireless data transmission to further lower down the power consumption. Instead

of continuously transmitting the collected raw data to the external receiver in real time, the measured data can be compressed first before being sent out via wireless link in the burst mode. Furthermore, in most cases, constant exposure to moisture and water, e.g. sweat, is one of the leading causes of electronic failure in wearable devices. The same situation applies to the implemented patch sensor proposed in this chapter. Further enhancement is needed during patch's integration process to protect the inner electronic components against moisture and water. One straightforward and efficient approach is to encapsulate the electronic components and make them as a stand-alone module by using waterproofing liquid silicone solution.

In addition to the aforementioned approaches to further enhance a wearable device's reliability and maximize the user's comfort, more issues have been identified as potential challenges which need to be addressed by further researches in order to improve the security, the efficiency, and the interoperability of the wearable healthcare systems. These issues include: energy scavenging technology; security of private information; encryption and authentication of all communicated data; further improvements on sensor's miniaturization and system's wearability, etc. These issues may help researchers and developers in the field with possible directions for further research.

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Chapter 5

Citizen Science, Air Quality, and the Internet of Things

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ABSTRACT

This chapter discusses the emergence of the Internet of Things, using a case study of a citizen science initiative, focusing in particular on issues involved in measuring air quality. The core of the citizen science initiative was formed by a world-wide network of early adopters of the Internet of Things who, motivated by public health issues, set out to create widely available tools for air quality measuring. With these tools, they established a global, citizen-led, air quality measurement network. Besides highlighting a number of social and technological issues which are involved in any such enterprise, this chapter engages with the discourse surrounding the use of IoT in collective sensing projects. Two questions are salient here. Firstly, can IoT technology be used in a citizen science context to monitor air quality? And secondly, does the construction of these devices lead to a successful mobilisation around issues of air quality?

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INTRODUCTION

The study of atmospheric pollution is admittedly an untidy science. (Meetham, 1952)

While there are many environmental factors that can affect our health and well being the air all around us is often perceived as a matter of lesser importance. It is only in the case of major incidents, such as leaks from chemical factories, the explosion at Bhopal, or radioactive fallout like that from Chernobyl or Fukushima that raise public concerns and demand action. This apparent contentedness might be due to two factors – as a major environmental matter air is seen as universal, shared and paramount. Invisible in its nature, it can be perceived as something that cannot be affected by ones individual actions. Second, despite the evidence and growing concerns over the effects of air quality, one could argue (even if incorrectly) that we are living in a much cleaner environment, when compared to the not so distant past. In recent years, however, there has been a growing interest in and concern about air quality. As this research will argue, the conversation about air quality has been renewed by recent developments in technology and citizen science.

The data in this study is drawn from ethnographic research conducted in physical and virtual spaces, primarily between 2011 and 2013, of a group of early Internet of Things (IoT) developers and an evolving community of air quality activists. It uses theoretically informed analysis of data from interviews, mailing list exchanges and comments on online platforms. We augment the methods of traditionally qualitative approach, with its desire to understand the social world and its meaning for its participants, with elements of discourse analysis in order to uncover the ways in which this world is produced. It is from such a viewpoint that this chapter will address the relation between the citizen science, IoT and the complexities involved in measuring the air quality.

AIR POLLUTION AND SOCIAL AWARENESS

The discourse around air pollution is centuries old, while the legislative process is slow and most often ineffective. In Britain, the first recorded effort to combat air pollution dates back to the reign of King Edward I in the year 1272, when at the request of some noblemen and clergy, the king banned the use of sea-coal. “Anyone caught burning or selling the stuff was to be tortured or executed” (Urbinate, 1994). The ban seemed to have little effect, as in the 14th and 15th centuries, other measures to regulate the use of sea-coal were introduced by subsequent kings (Kotin & Falk, 1964). In 1661, John Evelyn, a notable diarist of the days of King Charles II, published the anti-coal pamphlet: *Fumifungium: or the Inconvenience of the*

Aer and Smoke of London Dissipated. Pleading with the King and Parliament to do something about the burning of coal in London and its effect on the health of the citizens he wrote: “Aer, that her Inhabitants breathe nothing but an impure and thick Mist accompanied with a fuliginous and filthy vapour...” (Evelyn, 1661). However, his message did not have any effect, and the pamphlet was forgotten for more than a century (Staniforth, 2013). In the 19th century, the famous fogs were widely referred to as *pea soup*, or a *pea souper*, or as *black smog* and more frequent references to its effects on health and premature death were made (Stern, 1982; Urbinato, 1994).

In Britain, it was only after the Great Smog of 1952 that real reform was passed by the Parliament. At the time, it was thought that 4000 people had died from Great Smog. Later research placed the death toll around 12,000 (Bell & Davis, 2001). Parliament took action, passing the 1956 Clean Air Act (Davis, Bell, & Fletcher, 2002). Today, European air quality is managed by directives issued by the EU, set in place since 1980s with directive 80/779/EEC, which set air quality limit values (AQLVs) and guide values for SO₂ and suspended particulates (SP). Later directives set limit values for lead, nitrogen dioxide, and ozone (DNERI et al, 2004). In the United States, it was the investigation into the Donora Smog Disaster that led to the first federal clean-air act, passed in 1955. In 1948, the town of Donora, in the Monongahela River Valley, Pennsylvania, was covered in toxic smog caused by a weather inversion. It trapped a cocktail of sulphur dioxide, carbon monoxide, nitrogen oxides, fluoride chlorine and metal dust emitted from local coal burning plants and furnaces located in the valley and town. Over four days, 20 people died, and 7,000 were reported to be sick (Townsend, 1949). The clean air act forced the plants and furnaces to close down. It was in the late 1950s when the first links between air pollution and motor vehicle emissions were made, with the State of California enacting a legislation requiring its Department of Public Health to establish air quality standards for vehicle emissions. This led to the federal government’s *The Motor Vehicle Exhaust Study Act of 1960* and subsequent legislation. Just like with air pollution in the previous century, some of legislative acts proposed later were seen more as a nuisance and never got passed or taken seriously (Stern, 1982).

Fifty years into their accelerative growth, the number of petroleum-fuelled motor vehicles on the roads, globally, has become a major source of air pollution (European Environmental Agency, 2015). In early 2016, the World Health Organisation issued a warning about deadly levels of pollution in many of the world’s biggest cities. Pollutants not only exceed the currently set safe air quality values. They also kill millions across the globe (WHO, 2016). As the WHO has shown, air pollution has worsened since 2014 in hundreds of urban areas. The WHO warns there is now a global “public health emergency” that will have untold health and fiscal implications (Vidal & Helm, 2016). Only two weeks into 2016, and London had already exceeded its annual limit for nitrogen dioxide (Vaughan, 2016). As a study done by

researchers at King's College London show, 9,500 Londoners die each year because of air pollution, twice as many as previously thought. "The premature deaths are mainly due to two key pollutants, fine particulates known as PM_{2.5}s and the toxic gas nitrogen dioxide (NO₂)" (Walton et al., 2015).

Many have pondered why it has taken so long to recognise the deadly effects of air pollutants to human health and why there has been little action to combat this situation. In their very first attempt to encompass the analyses on correlations between air pollution and human health data, almost a decade after the Clean Air Acts were installed, Kotin and Falk (1964) pointed out the very problem with the concept of clean air in the *Annual Review of Medicine*. As they explained:

A major consideration in the recognition of potential adverse health effects of air pollution is the knowledge that pure urban air from a chemical viewpoint is virtually non-existent. Movement of air and dilution of pollutants in the large volume of the atmosphere are the two chief mechanisms of air purification. Interference with either, or, as most frequently occurs, with both simultaneously, results in the accumulation of progressively increasing levels of pollutants. (Kotin & Falk, 1964)

Bohm (1982), writing about the correlation between increased lung cancer and air pollution suggested that this inability to grasp the seriousness of the issue is rather a question of human perception: "Mankind accepts the risk of long-term and low-level exposure to carcinogens. As a rule, immediate benefits are sought and remote hazards ignored" (Bohm, 1982). Seaton, MacNee, Donaldson, and Godden (1995), reassessing the limited impact of studies correlating the effects of air quality and human health pointed out that there might be a problem with the scientific method of capturing this complex issue:

These findings have encountered some skepticism, partly because the concentrations of particles at which effects seem to occur are low by comparison with those to which many people are exposed in industrial workplaces without apparent harm; and partly because no plausible hypothesis has yet been advanced to explain the associations. (Seaton, MacNee, Donaldson, & Godden, 1995)

In response, by explaining how harmful particles behave in the environment and in the respiratory system, their study proposed the hypothesis that the "acidic ultra-fine characteristics of air pollution particles provoke alveolar inflammation, which causes both acute changes in blood coagulability and the release of mediators able to provoke attacks of acute respiratory illness in individuals."¹ They established the current leading theory on the mechanisms through which the particles harm human health – they cause an inflammatory response that weakens the immune system.

AIR QUALITY AND HUMAN HEALTH

It is widely accepted today that there are various air pollutants that differ, in their chemical composition, reaction properties, emissions, persistence in the environment, ability to be transported long distances, and eventual impact on human health. Yet, they share some similarities and can be grouped to four categories:

1. Gaseous pollutants (SO₂, NO_x, CO, ozone, volatile organic compounds);
2. Persistent organic pollutants (dioxins);
3. Heavy metals (lead, mercury); and
4. Particulate matter (Kampa & Castanas, 2008). Similarly, there is agreement in how each affect human health.

Indoor and outdoor air quality are linked. It is well established that “much of what is outdoors comes indoors. Estimates of the fraction of indoor fine particles that originated outdoors range from 46% to 84% depending on whether the house was air-conditioned and whether windows were left open” (Wilson, Mage, & Grant, 2000; Smith et al., 2014). Likewise, the rate at which outdoor air circulates through a house depends on the season and the weather. Indoor air pollution is not only affected by outdoor air quality, but also by furniture, cooking gas, chemicals used in the house, etc., all contributing pollutants to our environments (Spengler, Samet & McCarthy, 2000).

It is widely perceived that air pollution mainly affects the respiratory system and lungs. Short term exposure can lead to burning of the eyes and throat and difficulty breathing (Waldbott, 1978; Schell & Denham, 2003). It may also result in chronic lung disease (Kotin & Falk, 1964; Whittemore, 1981; Utell, Sawyer, & Warren, 1994), and trigger asthma attacks in adults (Schwartz, Slater, Larson, Pierson, & Koenig, 1993) and children (Wjst et al., 1993; Clark et al., 2010). Long-term exposure can reduce lung function and increase the risk of developing lung cancer (Nyberg, Gustavsson, Ja, Bellander, & Berglind, 2000; Smith et al., 2014).

As many epidemiological studies have shown, the effects of air pollution can impact other parts of the body (Utell, Sawyer, & Warren, 1994; Pope, Bates, & Raizenne, 1995; Schell, & Denham, 2003), causing heart attacks, irregular heart rhythms, and strokes (Seaton, MacNee, Donaldson, & Godden, 1995; Miller et al., 2007; Brook et al., 2004, 2010). The heavy metals such as lead, mercury and arsenic, as well as dioxins, can also affect the nervous system (Lasley & Gilbert, 2000; Kampa & Castanas, 2008), urinary system (Damek-Poprawa & Sawicka-Kapusta, 2003; Kampa & Castanas, 2008) and digestive system (Kimbrough, Carter, Liddle, & Cline, 1977; Kampa & Castanas, 2008).

A body of work has been carried out on the effects of air pollution on different social groups. For example, in infants and young children it can decrease nerve conduction velocity and impair mental development (Walkowiak et al., 2001), can be an indicator of poor health at birth (Chay & Greenstone, 2003; Currie & Neidell, 2004), and a reason for low birth weight (Almond, Chay, & Lee, 2005). It affects growth and development (Fogel, 1986) and leads to premature infant death (Currie & Neidell, 2005; Smith et al., 2014). Likewise, the effects of air quality have also been studied in the context of other consequences. It is a cause of multiple hospital admissions (Dockery & Pope III, 1994; Klot et al., 2002), absence from work and school (Park et al., 2002), restricting activity (Pope III, David, & Raizenne, 1995) and increasing medication use (Peters, Dockery, Heinrich, & Wichmann, 1997; Klot et al., 2002).

As many of these studies on the impact of air quality on human health have noted, the subject has often proven to be difficult due to the many complex factors involved in assessing the impact of one or other pollutant or due to the variety of health factors affecting test subjects. The relevant studies have also confirmed there is often some type of limitation involved, either due to the measurement of one or other pollutant and its effects over time, or with the variety of observed subjects and their individual circumstances. Likewise, studies have revealed their dependency on the research methods used, as there is often some element of prediction involved, either in the use of algorithms that correlate predictions and the actual levels of pollution, or with the quality of measurements conducted by AQ monitor stations. Thus any findings are often seen as estimates only (Currie & Neidell, 2004).

Writing at the turn of the century Gochfeld and Goldstein (1999) reassessed the lessons from environmental health from the 20th century in their article in the Annual Review of Public Health. There they acknowledged the rapid development of new technologies and new methods in the field of Public Health and in air quality discourse. Advances in analytics, data acquisition, modelling, toxicology and risk assessment, have all had immense impact on how studies can be conducted and how growing concerns over air quality could be addressed. They suggested three main areas lessons could be drawn from:

1. For science and technology to play lead roles in primary and secondary prevention, environmental-health scientists must participate in policy;
2. Environmental health problems and solutions are complex; interdisciplinary research is required; and,
3. Environmental health is a global issue. (Gochfeld & Goldstein, 1999),

With accumulated knowledge in this field of study and directives issued by air quality monitoring agencies, the impact of air pollution on human life is still per-

ceived as gravely neglected. In the following analysis into the rise of Citizen Science and community-led air quality monitoring networks, this research will argue that the perceived failure of established science to deliver change and the quest to affect policy-making processes, have led to ordinary citizens adopting the technologies and organising themselves. A closer analysis of these desires and of the adopted methods and technologies used in research suggest the impact such a bottom up approach could have to increase awareness of the subject and subsequently lead to action in this field. Before that, the following section will address the technological advances that, as our research suggests, has empowered this popular movement.

TECHNOLOGICAL AND SOCIAL CHANGE: ARRIVAL OF THE INTERNET OF THINGS

Technological developments of the last decade have led to more advances in the application of sensor technologies and the rise of the phenomenon of the Internet of Things (IoT). Ubiquity of computing and an increasing number of electronic sensors applied to the diverse physical processes of the planet's environmental systems, body monitoring, and the augmentation of everyday objects, allow data capture, storage and analytics, now most often in realtime. The Internet of Things envisions a connected world of billions of smart things, devices, smartphones, smart cars, smart homes, and smart cities (Fleisch, 2010; Haller, 2010; Evans, 2011; Mitten & Simplot-Ryl, 2011; Stankovic, 2014; Behmann & Wu, 2015; Miller, 2015). Gartner Inc. forecasts that 6.4 billion connected things will be in use worldwide in 2016, and will reach 20.8 billion by 2020.² Cisco has estimated the number being even higher, with up to 50 billion devices being connected by 2020 (Evans, 2011).

The IoT has been presented as a way to make intelligent hardware more pervasive by reducing hardware size, cost, and power consumption. Another important factor was the development of open source software and hardware platforms, in particular, the microelectronic platforms with an easy to use Integrated Development Environment (IDE). The low cost platforms such as Arduino (2004), Zigbee (2006), Nanode (2011), Raspberry Pi (2012), and the like, have democratised access to, and use of, these technologies. This has led to a situation where increasing numbers of computing projects involving network sensing and other interactive digital urban intervention projects are today developed not only by large technology companies but also by a wide variety of individuals, groups and communities empowered by these technologies (Kuznetsov, 2010).

The other requirement of pervasive distributed sensor networks and the IoT is that of network architecture, with its need for devices to configure their own network configuration. Thus not only have devices become smaller, more numerous,

and more pervasive, but also the networks in which they are located promise less hierarchical system approaches, and are thus also less susceptible to certain types of regulation. The latest developments in machine to machine learning (M2M) (Tan & Wang, 2010) and the development of autonomous IoT interconnected systems (S. Park, Crespi, H. Park, & Kim, 2014), in which machines and devices will be able to pass information and/or contexts between each other, will enable further machine autonomy in decision-making. It is this very idea of the interoperability of devices, networks and intranets - anytime, anyone, anything, any place, any service, and any network (Sundmaecker et al., 2010) - that is fostering the development in areas of IoT, such as standardisation, semantics, data platforms and management of interoperability both in technical and social terms.

CITIZEN SCIENCE AND COLLECTIVE SENSOR NETWORKS

The low cost of and open access technologies have given rise to two recent phenomena: Citizen Science (Riesch & Potter, 2014; Kullenberg & Kasperowski, 2016) and the Collaborative Economy (Bauwens, 2012). As Bauwens noted, “The players of this emerging collaborative economy are diverse: their objectives, attitudes towards collaboration and sharing, their methods of work as well as their business models are heterogeneous.” Two major types of approaches can be distinguished in Citizen Science (CS). While many Citizen Science projects refer to an approach of science that mobilises crowds outside science to assist with observations and classifications, what we will discuss here is the other account, which refers to CS as a way of democratizing science - “aiding concerned communities in creating data to influence policy and as a way of promoting political decision processes involving environment and health” (Kullenberg & Kasperowski, 2016).

Alan Irwin (1995), in his seminal work *Citizen Science*, made explicit the link between the environmental challenges, global developments and rise of citizen-science initiatives. Irwin argued that these global challenges and in particular the environmental threats “can not be successfully tackled without a full consideration of *local* as well as global initiatives of *citizen-oriented* programmes”. In 2010, Kera and Graham also introduced the term *Collective Sensor Networks* (CSN) to describe activities that involve sensor technologies and involve diverse groups of participants working to integrate sensor data from various environmental sources. Examples of such projects include citizen-led citizen science initiatives that often focus on solving environmental problems affecting people locally. In this respect, as acknowledged by the EU research policy study, “the questions that citizens – not

just scientists – seek to answer can set the agenda for environmental research and policy debate” (Science Communication Unit, 2013).

There are a numerous examples of citizen-led initiatives that have tackled the local concerns of air pollution. For example the well documented struggle of African American residents of the Diamond subdivision in Norco, Louisiana, who through the late 1990s until 2002, “waged a heated campaign against the Shell Chemical plant adjacent to their community” (Ottinger, 2010). By use of analogue tools for air quality measurement such as buckets³, “activists measured short-term spikes in air pollution levels and compared their data to arguably incommensurate regulatory standards to demonstrate that the air was unsafe” (Ottinger, 2010). However, retelling their story Ottinger argued that, despite the rhetoric of how citizen-science could influence the research directions and policies, there is a visible disparity between methods and data created by the citizens and scientists. As she pointed out it is standardized practices for measuring and evaluating air quality that determine to what extent and in what ways the nonscientists’ knowledge production is assessed. Ottinger argued that “regulatory standards for air quality, combined with standardized practices for monitoring, provided regulators with a ready-made way to dismiss activists’ data as irrelevant to air quality assessment” (Ottinger, 2010).

The advent of IoT has brought about a new opportunity not only for development of easy accessible set of new digital tools, but also their networked capabilities with its real-time data storage and analytics. It is, then, not surprising that the IoT was, early in its development, embraced by the CS movement, and used for intervention in the public health sphere and air quality monitoring. The following chapter will focus on discussing and analysing a case study based on one such citizen science initiative. The core of this initiative was formed by a global network of early adaptors of IoT who set out to create widely available tools for air quality measuring. With these tools, they established a global, citizen-led, air quality measurement network and subsequent sensing intranets.

Besides highlighting a number of social and technological issues that are involved in such an enterprise, such as a community approach to measurements and calibration, this chapter will foreground practical difficulties involved in such enterprise. While building tools and contributing to the spread of CS know-how is fundamental here, the difficulties this community faced is not accidental, but rather deeply routed in dichotomy of science versus CS discourse, already highlighted by Ottinger (2010). Thus we would argue for CS to be taken seriously and better organised it is important to evaluate the strength and weaknesses of past events, so that lessons can be learned for future causes.

CASE STUDY: PACHUBE AND THE AQE COMMUNITY

The community in question consisted (2011-2012) of developers and citizen science activists who associated themselves with one of the earliest IoT data platforms. It was formerly known as Pachube, Cosm, and, later, as Xively. In its Pachube incarnation, it was ‘one of the first available Cloud-based services for managing sensor data, that provide[d] a light application programming interface (API) for sending data directly from sensors and its web environment allow[ed] the visualization of data in graphs’ (Doukas, 2012). The London-based architect and designer Usman Haque initiated the Pachube project in 2006 as a monitoring system for his interactive art installations. Later it was opened up to other participants and by 2008, it provided a public platform and became a meeting ground for DIY sensor data enthusiasts. By mid-2011, Pachube accounted for an average of 6,000 users worldwide. At that time, it became a start-up company, as the Boston based cloud-service provider LogMeIn acquired it (Butcher, 2011).

Diverse interests motivated the users of Pachube. Initially, the largest group was enthusiasts engaging with their home energy monitoring systems (Dittus, 2012). In 2011, after the devastation caused by the tsunami in Japan and by the consequent meltdown at the Fukushima nuclear power plant, Pachube became network central for a citizen-run network of connected Geiger counters that measured nuclear radiation in real time. These sensors were set up by concerned citizens, in Japan, and later globally, as a response to the poor quality of the emission data released by the Japanese government. In less than 24 hours the interactive designer Haiyan Zhang created the first data map, visualising the Geiger counter data. The map pulled all of its real time data from the Pachube platform and showed the movement of radiation spills.⁴

The same year, Pachube’s rather accidentally assembled user community gained a more coherent shape, as series of the earliest IoT meet-ups in New York, London, Madrid, and Amsterdam were set up. The broad and spontaneous public participation in the aftermath of the Fukushima disaster inspired a second citizen science interest group focused on air quality. It was during the January 2011 meetup in New York that the Pachube community organiser Ed Bordon and technologist Joe Saveria suggested the development of a community driven air quality network. This led to the development of the Air Quality Egg (AQE) project, a sensor hardware device (Egg) and an air quality egg network. A year later, as a development of early prototypes of this affordable, open and easy to use measurement tool for air quality was underway, the group launched a Kickstarter campaign to drive up the interest of the wider public, to round up a group of supporters and to spread the great news of growing citizen concern about air quality.

In contrast to other existing projects the AQE project grew out not from a particular ‘local community’ concerned with a particular problem, but rather from a globally dispersed group interested in use of connected monitoring device. As people started to join the campaign, it was valuable to see what motivated these early adopters of technology and supporters of the AQE project. While the majority of Kickstarter supporters were often technologically aware enthusiasts interested in social tech, there were also many who were driven by common concern for the planet or for their own welfare and who were looking for technology that could support their struggles. When we analyse the responses to a question of what motivated them to join the campaign, we could distinguish three major themes. The first would be the already mentioned technologists involved with development of social technologies, as these examples illustrate:

E1: *I’m XXXX. I’m a London-based UX designer, who is interested in using pervasive technology to help improve people’s lives. This seems like a very interesting experiment.*

E2: *I am a semi-retired instrumentation technician living in the high desert of N.M. I have a Pachube feed now just for hobby purposes. Interest in air quality is just concern with keeping the planet livable.*

As these comments show, such a community project seems to appeal to a skilled people who see the opportunity for their skills to be applied, even in retirement or in their free time. Similarly, it was attractive to technologists and activists involved in some already existing communities or to education projects, as illustrated by the following:

E3: *I am an architecture student working for a non-profit community design center called building community WORKSHOP. I am leading an energy education initiative, and we are working on a plan to implement home energy metering and feedback at community scale. I think air-quality goes hand in hand with efficient energy use and “healthy neighbourhoods”. We are working on solutions to bring forward the benefits of sensor technology in making educated behavioral choices related to building energy performance in low-income communities.*

The second group are day-to-day activists who in general are interested in the common good, the health of common resources, and in activism as such. While expressing global concerns, this group is more concerned with local issues. Examples can be drawn from comments such as:

Citizen Science, Air Quality, and the Internet of Things

- E4:** *Hi, I live in London England and always wonder just what I'm breathing in, in this unnatural world we live in!*
- E5:** *I want to know what kind of air quality we have here in Valparaiso, IN, with Chicago being just upstream from us and all.*
- E6:** *Hey - I live in Atlanta, GA - Would like to monitor air quality. I'm about 2 miles from downtown and the junction of I20 and I75/I85.*
- E7:** *I am interested in the 'activist' angle - data that compliments or supersedes that provided by established power structures.*

The third group, and the one we are most interested in the context of this article, are people with existing health problems who are looking for the tools to explore their own environments and thus to tackle or self-manage concerns driven by their or their own or family's health.

- E8:** *Hi, my interest is in the levels of pollen, mold and humidity as I am asthmatic. Cheers from New Zealand.*
- E9:** *I am in Switzerland and they smoke so much here, they also use a lot of chemicals, from paint to the oils for heating..... I am sure this has affected my breathing these last years.*
- E10:** *My children have developed asthma symptoms, and I would like to know how the air quality is to see what correlation can be inferred from the data.*
- E11:** *My family lives several miles from the Rhode Island Central Landfill, which was never an issue until around September of this year, when foul gas odors began emanating from the landfill and spreading far beyond the landfill's boundaries. Sometimes the smell is so pronounced and gag-worthy as to induce headaches and nausea. I have a hard time believing that a gas so noxious could possibly be benign, and I'd love to contribute in any way to help measure and map air quality in our community.*

These examples corroborate the broader trends observable across responses received from 927 backers of the Kickstarter campaign. The growing community involved in supporting this project had a global character. Likewise, it seemed to engage citizens in both urban and rural settings interested in both indoor and outdoor air monitoring. Some of them had some other group affiliation, some didn't. As the community set off to develop the AQE device more direct references to overriding health concerns linked to air quality could be observed over time. Discussing the process of development or negotiating the thinking process, actors kept bringing up their motivational concerns. On the AQE group mailing list such cases appeared across time. As in following example after the launch of the AQE, one of the de-

velopers arguing for the validity of the chosen ‘community approach’ decided to tell a story to argue his point.

E12: *Years ago, I was interviewing a young woman in Chicago whose son had serious asthma. She checked the EPA website every morning to see what the air quality was that day. She made decisions about which streets to walk her son to school along and whether to ask teachers to keep her son indoors. The problem with this is that because the sensors were so expensive, the EPA data for Chicago came from six sensors, none of which were near her home. She didn’t know which streets were better. She didn’t know what the indoor air quality was like in her son’s school. She needed the kind of data that can only be collected by many inexpensive sensors. She needed something just like Eggs and any of those three levels of data would have worked better than what she had.*

While these are comments from only a few members, they illustrate well the three general themes, as well as how often overlapping their interests and motivations are. Likewise, they highlighted some other underlying concerns that echo across the community discussion we have observed on and offline. Example 3 touches upon the idea of behaviour change that such sensing technologies could encourage. The idea of behaviour change echoes across many other IoT projects today, suggesting technocratic framing for these developments and how well such citizen science network sits within the broader IoT discourse. Examples 7 and 12 similarly highlight the issue of concern that can be found across our study, that of power relations. Drawing parallels with established data sources, or criticising the shortcomings of existing air quality measurement stations or their network density, there seems to be a common distrust of government data. As we will see in discussion below, these underlying motives were also used to define more practical decision making processes and to negotiate the space for the community approach.

Community Approach: An Opportunity to Do It Differently

As community development of the Air Quality Egg device was underway, there were numerous discussions of what the distinct characteristics of this community-run network would be, of the device itself, and how to determine their unique properties. The slogan for the AQE Kickstarter campaign (launched March 2012) stated: “A community-led air quality sensing network that gives people a way to participate in the conversation about air quality.” However, around that time there were a few other air quality measuring projects that sought to empower communities by providing tools and in a similar manner set about fostering conversation.

There have been a number of studies conducted on development of sensor devices, for example, measuring the pollution of motor vehicles such as diesel buses. In California the Dump Dirty Diesel Campaign commissioned ‘The School Bus Monitoring Study’ to highlight the health hazards posed to school children by daily exposure to diesel pollutants (Solomon et al., 2001). While this study focused specifically on bus emissions others use buses for broader citywide air pollution monitoring. The Swiss Scientific Initiative’s project OpenSense, has installed sensors on the roofs of city buses and trams, to create public air quality monitoring resource (Aberer et al., 2010). Similar pollution sensing projects using buses have been trailed in the city of Sharjah, UAE (Zuolkernan & Aloul, 2010).

Around the same time as AQE development took place there were other more citizen-oriented projects. In 2011, in New York, Google funded non-profit environmental health justice organization HabitatMap to develop an Air Casting application for mobile platforms. As part of this project Air Casting Air monitor was developed and later open-sourced as build-your-own hardware platform (Yap, 2012). In Europe, same year EU Seventh Framework Programme, funded consortium of European institutions to develop Everywhere project. Part of this larger project, researchers developed an air quality monitoring kit – SensorBox for community-led air quality monitoring (Elen et al., 2012).

While AQE project developers were aware of these other explorations in the field, from the projects outset they tried to argue for a different approach. In the following examples, the authors have tried to distil the core difference this community chose to highlight. While various actors often repeat these themes in meetings and conversations, these particular examples are taken from the key developers of the project and thus best elaborate the underlying themes. As we can see in Example 13, key to this development was the idea of multiple developers and voices participating in decision-making, which was seen as a pedigree for the democratic nature of the project and the global characteristic of this community.

E13: *The most valuable part of it is the way it is extremely democratic and community driven project. Even from the concepts, to every part of development now: the hardware, the software, the productization of it. All those things are happening simultaneously from multiple communities.*

Example 13 talks primarily about the community of developers and the difference it makes in comparison to other similar projects that were seen as much more top down in the way they were executed. For example in case of Everywhere project the developers of the air monitoring kit applied a scientific approach. As it was the established scientists and academics in field of air monitoring who developed this kit, there were only limited numbers of units built and used in trials by selected

community members. In contrast the AQE community members were self-selected. Example 14 turns to the value of users/participants within AQE community and what they could bring to the interactivity and way the system operates and its supporting applications. This example is taken from the mailing list conversation at the conceptual development stage of the AQE development, and as such, well illustrates the aspirations of the project rather than the final outcomes.

E14: *We're not (i think) simply trying to build yet-another-air-quality sensing system that passively monitors the environment; or simply trying to replace an official network with a distributed/citizen-led initiative. we are (i think) trying to do something authentically participative that goes to the heart of why exactly people (i.e. citizens/normal people/everybody) would even want to *know about* and *do something about* air quality. by way of analogy, there's a difference between a security camera that continually streams footage in the hope of catching something significant; and a hand-held still camera that encourages - actually *requires* - the bearer of the camera to think about the moment of taking a photo and then trying to recognise and capture something significant. there is a completely different participation with and interaction with the generated 'data'.*

This “requirement to think about” by providing a human feedback option to the otherwise passive observation system did not materialise in the AQE V1 and its system. However, the question about tools for user participation resonated across many discussions, and often provided a fertile ground for “thinking” further and conversing about such system applications, and in particular, the tagging mechanisms that could be employed. The third key argument about the uniqueness of such a community-driven approach to air quality measuring was that of network density. As Example 15 shows, the argument about the density of distribution of air quality measurement devices that such a network of everyday people could provide is what sets this project apart from “government” run networks or any other top-down infrastructure.

E15: *Even if our data is not validated scientifically or in that technical direction, I hope that we get the right information to say – there needs to be more study. The air quality sensors like this are really – it can be the go to for application real high-end sensors. I mean, the government has picked the places to put sensors, but what if we say, well, there are real pockets here that you need to be careful about. Or 'right around the school there is a traffic intersection that we have really, really weird readings and we changed our sensor three times and we still getting real weird readings', you know, further investiga-*

tion! And that's a win right there. You know, weather or not data is great or not I don't really care.

Like Examples 7 and 12, Example 15 hints of the power relations and how such tools in the hands of many could generate knowledge about very local issues that often are overlooked by a more centralised viewpoint. Opting for a development of a broadly available product rather than specific or experimental community solution, or release of just How To guide to monitor building was seen as only feasible way to reach mass user base. Likewise, Example 15 offers insight into the key, and the same time, most contested, value the project has created – that of data created by the device, system and community at large. The data will be discussed later on. However, it is important to note that it is this belief in data acquisition that is seen to empower the actors' agency.

Community Approach: AQE - A Measurement Tool and Its Calibration

One of the key components of the AQE project was the development of the air quality measuring device, the Egg, or AQE, that could enable popular access to the atmospheric data. It consists of a number of low cost sensors, mainly temperature, humidity, NO₂ and CO sensors⁵, and a microelectronic board with an added Ethernet board for connectivity and on-board LED lights to indicate status. The components of the egg are modular, and all codes are open and published on GitHub. The device has an egg shape plastic closure and power adapter. Depending on their level of technological understanding, users can either 'plug and play' the AQE or tweak it for specific case requirements.

In applying technology to any given natural phenomenon, there are two fundamental issues that are of concern. First is the question of measurement, i.e. what it is that is measured. The second is the question of the measurement tool's calibration. Within our given subject, both considerations encompass a complex set of issues. The most common way to measure air quality is perceived to be by measuring the presence of contaminants in the air. As already cited, the AQE V1 (2012) focused on two main pollutants, CO and NO₂ and on temperature and humidity. However, AQE was built as a modular unit thus other sensors could be added. (It should be noted here that today [2016] AQE V2 for PM_{2.5} and PM₁₀, O₃ and SO₂ are also available).

While there is a standardised way of measuring pollutants, the approach much depends on measurement tools and approaches. Each pollutant can be measured in a variety of ways and units. The concentration of NO₂ is most commonly measured in micrograms per cubic metre of air (µg/m³). The AQE device measures CO and NO₂ in ppb (parts per billion), the other possible way for measuring air pollutants. The

measurement is defined by national standard, for example in the US EPA standard for NO₂ is based on ppm, while the European one are based on milligrams, however, there is a standard way to convert readings from µg/m³ to ppb.

It was early on in a group's discussion when the decision to focus on the two main pollutants was made. As one of the main objectives was the creation of an easy to use and affordable device, the decision was made to apply low cost, off-the-shelf available sensors. The discussion regarding what sensors to incorporate into the device soon turned to the calibration of these sensors. It seemed clear from the start that off-the-shelf sensors might not provide the desired accuracy. On a mailing list, the conversation kicked off with suggestions of a number of ways that calibration could be developed. Example 16 presents one of the earliest suggestions that also illustrate the general stand of the community with regards to data reading.

E16: *The egg is hopefully going to tell us that “some of something” is there, but as useful as knowing there is ‘some’ there knowing _how much_ of it, and accurately, is going to be as important.... In the UK it is a legal requirement for cars to be tested annually. The equipment for that testing is available, at every MOT test centre. One possibility might be to take along one's egg to the MOT and use the test's data report as a means to at least know a single reference point.*

The DIY approach suggested in Example 16 soon received many responses. One of the predominant suggestions was that of *scale-free calibration* for which some high-end calibrated sensor used by a known source could be used to compare the data created by an AQE, as suggested in Example 17 by use of term ‘official data’:

E17: *I think we could calibrate the eggs using the official data... and perhaps it is not necessary to quantify that there are xxxx ppb NO2, but just qualify that NO2 level is low, medium, high or very high.*

Other methods suggested included that of ‘Blind Calibration’ and ‘Network Calibration’. Blind Calibration, as discussed by Balzano and Nowak (2007), is one way of thinking how to make sense out of raw data read from sensors with no calibrated source. They applied the term *Blind Calibration* to “automatic methods for jointly calibrating sensor networks in the field, without dependence on controlled stimuli or high-fidelity ground-truth data”. They propose an algorithmic solution a “novel automatic sensor calibration procedure that requires solving a linear system of constraints involving routine sensor measurements” (Balzano & Nowak, 2007). The group itself put the ‘network calibration’ approach forward. It is explained in the following Example 18:

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E18: *“Network calibration” aspect: using the size and distribution of a large sensor network to improve on the sensing quality provided by its constituent devices. Picking up on a few discussion threads I suggest three phases/strands:*

- Collect known system limitations (how good/bad are our sensors really?).
- Collect recommendations for metadata to collect (“traceability”).
- Review potential network calibration models, pick one.

However, soon into the discussion of both these methods the comment was made about the lack of supporting sources for these approaches:

E19: *There is no useful theory that anyone has put forward or a technical paper identified that supports the concept of “Blind Calibration” for a simple stationery sensor - that is making sense out of raw data read from sensors with no calibrated source. There appears to be a lot of wishful thinking.*

The problems with ‘network calibration’ similarly lacked technical papers to support this approach. Up until today, there has not been a network-wide calibration, and most of the AQE V1 observable on this network, use the sensor factory settings. As Examples 20 and 21 show people continued to contemplate and experiment with calibration, to draw the meaning from the raw sensor data, thus contributing to the community’s shared knowledge pool.

E20: *Yes, I think in the long term calibration is very important to this project. While I am not an expert at calibration, I am involved with a project that will be testing some Sensaris Sensors against Alberta Environments reference method to see how the data compares for NOx. I had suggested that we test the AQegg sensors as well. I believe that we need to know what the sensor’s data is saying, and how it correlates to a reference method. What is the variance, drift, etc.*

E21: *Based on the number of sensors (and data) that will be available and the fact that data will be ‘raw’ (uncalibrated, etc.) this looks like a very interesting project and challenge for applying pattern recognition techniques in order to either identify patterns (based on location of eggs, sensors used, etc.) and/or classify air quality (based on user estimation, correlation with other data, etc.).*

While the discussion about calibration is ongoing, the version 1 of the AQE was launched without specific method adopted and all sensors were not calibrated. The key argument to this approach, also reflected in statement on Kickstarter campaigns website, was made by a community organiser who wrote the following statement on campaigns discussion board:

E22: *A note on calibration: Impossible. We cannot build a consumer-focused product that requires regular maintenance/calibration of the sensors. Moreover, off-the-shelf sensors like we are using do not come calibrated, and so we would incur significant expenses to attempt to calibrate them after integration, only to still have the problem of re-calibration later on. Therefore, we can, and will, only look at trends in the data. Smart people, I'm sure, will find savvy ways to interpret this data for us, match it up with calibrated datasets (government or scientific institutions may be able to provide these), and /or learn things we never thought we would learn due to the sensor resolution, update frequency, and resolution we aim to achieve.*

However, this did not stop the community members from sharing their findings, thoughts and processes on this matter, and in the process create a resource of collective shared knowledge. In fact over 90% of all discussion on calibration took place after the Kickstarter statement was released. The discussion continued on mailing list and technical forums, and led the developers of AQE V2 to reconsider the importance of this matter. AQE V2 was launched later in that year with two additional AQE modalities, for PM, and for Ozone and SO₂. AQE V2 now uses fundamentally different sensor technology that is factory calibrated.

Furthermore, there have also been numerous community-led local AQE deployment projects that have published and shared reports on their findings and processes. The Citizens For Clean Air, in the Grand Valley in Northwestern Colorado run experiments with five eggs installed at different locations across valley. Not only they published and shared their findings with AQE community⁶, but also made it to a local news channel⁷. In London, *Breathe Heathrow* project distributed AQE among residents of Heathrow airport area and as a result succeeded in informing broader policy debate and subsequent delaying of airport expansion in South East England⁸. Some members have developed AQE reading and geo tracking maps⁹, and browser extensions¹⁰. Others have applied and perfected community-driven approaches to air measurements similar to the AQE community while using other types of devices.¹¹ These latest actions, recorded years later, show that processes started by such citizen science community group might not have immediate effect, but could deliver value as time goes on. Likewise, as authors would argue, such community-led developments can mobilise and connect citizens interested in air quality or other aspects of environmental research and public health.

CURRENT TECHNOLOGICAL LIMITATIONS

Sensors and Calibration

The complexity of issues involved in the calibration process goes beyond just the method of calibration. In any technological setting faults can occur frequently, at different levels. While it might appear that the device is still monitoring, the data it transmits, might be incorrect. Kingsly and Kaviyarasi (2014), analysing the fault detection techniques in Wireless Sensor Networks noted that:

In general, fault occurs in sensor network can be classified into two types. They are function faults and data faults. Function faults normally refer to abnormal behaviors of the sensor node, and this leads to network failure or breakdown of a node. Whereas in data faults, nodes behave as a normal nodes but they sense wrong information when compared to other nodes in the network. (Kingsly & Kaviyarasi, 2014)

AQE mailing list members similarly brought up the issues of faults, and numerous problems with ‘any type of’ calibration were identified. Those included not only technical i.e. those associated with hardware and software applications or processes, but also social and socio-economical ones, such as regulation standards in different countries. Here is a list of few problems identified:

The sensors will degrade over time.

The devices don’t always perform the method correctly. They get out of whack; they’re technology.

In developing software one sets up procedures.

Calibration is only valid for a limited time.

There are different definitions of calibration.

I realized air quality limits differ from US to EU and elsewhere in the world.

The issues of social context and its values were discussed within a broader Pachube community. The ‘faulty node issues’ were highlighted, for example, in a case of the radiation network in Japan, as they surfaced during the network data visualisation process¹². In Japan, the members of community, alerted by the irregularity of readings from one such node, contacted the owner of the node to discover that it was affected by falling raindrops. Such power of many, as this example suggested, can have a positive impact for ‘community network approach’ argument and its practical values.

In a recent [2016] comparative sensor performance study, conducted by South Coast Air Quality Management District researchers, three Air Quality Egg V2

sensor devices were run side-by-side with Federal Reference Method (FRM; EPA approved) instruments measuring the same pollutants. Study found that overall, the three Air Quality Egg V2 sensor devices tested, each one measuring CO and NO₂, “were reliable (i.e. no down time over a period of about two months) with a high data recovery ~100%, but showed substantial intra-model variability”. Furthermore, there seemed to be “a complete lack of correlation between the CO and NO₂ sensor data and the corresponding FRM data,” noting that further “chamber testing under known target/interferent gas concentrations and controlled (temperature and relative humidity) conditions is necessary to fully evaluate the performance of the three Air Quality Egg V2 units.”¹³ However, the study conducted on PM_{2.5} sensor showed that Air Quality Egg V2 not only correlates well with the FEM PM_{2.5} data, but also outperforms other available sensor devices on market such as Dyllos, Air-Beam, and MetOne.¹⁴

Data Quality Reassurance

This study has only focused on one community and its contribution to the development of air quality measurement tools, and it has not analyse in-depth the other important aspect of this and similar projects. As it has been pointed out, the AQE sensor would not exist nor have any impact in isolation from the ‘web or networked fabric of Pachube’ (McCue, 2012), its online data repository. It is where the data stream graphs are updated every three minutes and data is displayed in human readable form. The Pachube data platform, and any other equivalent data hosting platform, is another important layer in the overall story. Not only it is at these online repositories where raw data get converted and displayed, it also where the data is archived and made available. Other important matters, such as data security, storing and service providing for data interoperability, are also conducted by these data hosting platforms, thus adding additional layer of complexity to the overall process, however seamless it might appear.

At the time of the early development of the Air Quality Egg (2011-2012), one Pachube/Cosm data corpus analysis noted: “Many Cosm feeds have not been annotated with a sufficient degree of detail. Even the scale and units of measurement can differ within groups of sensors that observe the same physical property.” Likewise, the analysis of the study pointed to the lack of clarity and uniformity of metadata that supports the data streams. On the other hand, the study concluded: “This result does not put in question that there may be a potential ability of such community sensor activities to yield data suitable for building large-scale spatiotemporal models, but it clearly indicates that such data aggregation is only possible when the metadata supports it, and currently Cosm metadata is too heterogeneous” (Dittus, 2012).

Data platforms such as Pachube/Cosm and others, enables the access to data, and data aggregation from which further meanings could be derived, which, in turn, could present the data as an information or political tool. However, this part often presents itself as the most problematic. As Examples 23 and 24 reveals, seeing the patterns of change in data is not enough, and further discussion is needed about what can be done with such data, or what actions one could take in response to such data. What are the philosophical and ethical implications of data-empowered global citizens?

E23: *My question is how can I interpret these numbers. My family is mostly asthmatic and this would indicate to us that we should move right away... not trying to be alarmist but since we aren't totally sure what were looking at some info would be helpful. We want to know the meaning of the data over time. Especially anything we can do to calibrate things so we can see changes seasonal.*

E24: *After all with air pollution the origins are not always clear, your agency as an individual is very very little and CO2 is not to argue with on a local neighborhood scale. So you install an air pollution sensor and the air is consistently very bad (like it is and will be where I live). I know, now I can see it for it for myself. So what? What can I do? Move? Where to? Sell the house and not tell the new buyers why I move? How ethical is that? Having data in itself does not bring knowledge or change. Only agency to act on that data will bring information, knowledge or change. Without a 'how to do' kit that goes with the tech (is it not plain tech push otherwise?) about possible community action, counter activities with plants, herbs and planting certain vegetation community garden style, boycotts of products of companies that produce traceable pollution in an area, making pollution visible by putting up real blockades with wood and blocking intersections, cough consistently within and with a whole street for a week... I don't see why it would makes sense to have this data.*

CONCLUSION

Assessing the effect of air quality is, as many studies have confirmed, not an easy task. Research in health studies has shown dependency on the method used and, bias from predictions due to algorithms that correlate between predictions and the actual levels of pollution. Thus any findings are seen as estimates (Currie & Neidell, 2004). Likewise, these studies would have been based on data measured by air quality monitoring stations run by established government agency. As our study has indicated, the data generated by these stations have limited scope (mainly due to their low distribution density), and have thus stimulated a whole field of citizen community projects that aim to question government data by the use of 'citizen sen-

sor devices' that promise sensor access to very local environments. However, our study also points out that data created by citizen-led initiative often lack accepted scientific standards.

Technically, air quality itself is a highly variable phenomenon: measurements of air quality can vary greatly even at locations close to one another, and over a variety of timescales. Finding global, or average, figures can thus seem to be problematic. Politically, air quality is a difficult concept to mobilise around: the pollutants are invisible, and their effects are usually widely separated, temporally and spatially, from the exposure. Nevertheless, as the authors argued, the rise of the IoT has fostered community development of air measurement devices that in its turn have created space for discussion and practical application. This can lead to a shared knowledge distribution base, from which empirical learning and further initiatives can spring.

One aspect this chapter did not address is the socio-economics surrounding such citizen science projects. Issues include necessary support systems and organisational structures. AQE development at its outset was supported by the Pachube enterprise, financially and technically. Likewise, it was driven by the enthusiasm of its key players. How can such structural forms be foster for future sustainability so that such citizen-led air monitoring networks could be integrated into overall air quality monitoring system or their data made interoperable, with relevant metadata and human feedback? Further research and discussion would be an opportunity to address some of these issues.

While this chapter contributes to the field of collaborative sensing and of the collaborative IoT, it also hopes to contribute to the discussions in the field of public health. As more and more devices get employed to support human health and wellbeing, it is more important than ever to be aware of processes and complexities involved in measuring and calibrating such devices and systems. While community-led projects might not deliver the intended accuracy with of-the-shelf solutions, they can in some way foster discussion, widen knowledge, educate and mobilise for common goals. Further explorations of how such knowledge and abilities could be put to practical use and application are necessary to unveil the nature and potentiality of IoT applications in the field of health science and public health.

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KEY TERMS AND DEFINITIONS

Air Pollutants: Gasses, particles, organic pollutants and heavy metals in the air composition.

Air Quality: A popular term to describe a quality of air and its pollution.

Calibration: Process to determine the relations between two unknown quantities.

Citizen Science: Science research conducted by diverse group of people for perceived common good. Could include professional and nonprofessional scientists.

Collective Sensor Networks: Projects, groups and communities that use sensing technologies to create data from heterogeneous environmental sources.

Internet of Things: Internet of connected things, objects, vehicles, buildings, cities or any other entity in physical world that has been embedded with electronics for data collection and exchange.

Measurement: Depending from discipline, the value or number assigned to a property of an object or event.

Sensor Technologies: technologies with sensing capabilities to detect the events or changes in its immediate environment.

ENDNOTES

¹ Slightly paraphrased for clarity

² Gartner, Inc. forecasted that 6.4 billion connected things will be in use world-wide in 2016, up 30 percent from 2015, and will reach 20.8 billion by 2020. In 2016, 5.5 million new things will get connected every day. Read more about this prediction here <http://www.gartner.com/newsroom/id/3165317>

³ Since their invention in early 1990s, buckets have become widely used by the environmental action groups, sometimes referred to as “Bucket Brigades”. The air is collected in bucket that is lined with Tedlar bag. Air collected at regular intervals and samples sent to labs for analysis. For more details on Bucket Brigade see O’Rourke and Macey (2003).

⁴ The original Pachube blog post has been taken offline after Xively redesigned their site. The recorded snapshot can be traced via web.archive.org

⁵ The summary of AQE community discussion on hardware and sensor issues can be found on AQE wiki site. <http://airqualityegg.wikispaces.com/Hardware-Sensors>

⁶ Referencing here two documents published by Grand Valley community members: ‘Frequently asked questions about the Air Quality Egg Project in the Grand Valley’ and ‘Monitoring Air Quality In The Grand Valley: Assessing The Usefulness Of The Air Quality Egg’ by Nelson (2015).

- ⁷ TV episode is accessible online. Retrieved on August 10, 2016 from [www.westernslopenow.com news website](http://www.westernslopenow.com/news).
- ⁸ This was a temporary project developed by OpenSensors.org and postgraduate student Natalia Oskina. Read more on its impact on Open Data Institute's blog. Retrieved on August 10, 2016, from <https://theodi.org/blog/a-year-in-open-data-breathe-heathrow-informs-policy-making>
- ⁹ During the winter semester 2012/13 the bachelor students at the Institute for Geoinformatics developed modelling and visualisation of AQE network data. Their code can be found on GitHub
- ¹⁰ The founder of FTP software, John Romkey wrote a Chrome browser extension that can be downloadable from his personal blog. Retrieved on August 10, 2016, from <https://romkey.com/code/air-quality-egg-helper-browser-extension/>
- ¹¹ Madrid based *The Data Citizen Driven City* project used AQE to set up *The Device Library*, citizen device *How To* database.
- ¹² At 4th IoT London Meetup, designer Haiyan Zhang presented her work on radiation network visualisation. She described a case of such faulty node that was sending data 'off the beat', and how the data gave a 'clue' that there might be some problem with the node.
- ¹³ AQMD test preliminary results retrieved on August 1, 2016, from: http://www.aqmd.gov/docs/default-source/aq-spec/field-evaluations/air-quality-egg-v2_co-no2---field-evaluation.pdf?sfvrsn=0
- ¹⁴ Full list of AQMD tested devices and test results can be downloaded here: http://www.aqmd.gov/aq-spec/evaluations#&MainContent_C001_Col00=2

Chapter 6

Preventing Health Risks Caused by Unhealthy Air Quality Using a CEP-Based SOA 2.0

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ABSTRACT

Air quality has been a recurrent issue in recent years since it can seriously impact citizens' health and their life quality. Nowadays, the different ways to provide end users with air quality information do not provide real-time data and lack accessibility. Besides, they do not automatically adapt to the particular circumstances of each citizen. In this chapter, an event-driven service-oriented architecture is proposed for detecting air quality changes in real time as well as making this information available to end users in a user-friendly way, notifying them with customized alerts upon detecting any potentially hazardous level for their health, thereby helping to prevent health risks.

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INTRODUCTION

Because of pollution, among other factors, air quality plays an essential role in citizens' health. Particularly, air quality may improve or worsen the effects of certain illnesses and even cause the death of specific risk groups (WHO, 2013). In this regard, air quality monitoring is a fundamental aspect for a significant increasing number of citizens, such as elder people, people doing sports outside, children playing outdoor, or people who suffer from heart disease or allergies to certain substances that they may inhale while breathing. Although these are risk groups, air quality affects all citizens in general to a greater or lesser extent in everyday life.

As well as the weather does, air quality changes very frequently. This is why being informed about the quality of air in real time is essential to prevent personal risks. Three major factors should be addressed when informing citizens about air quality:

1. Information should be available in real time,
2. Information should be accessible in an easy and user-friendly way,
3. Information should be customized depending on the specific circumstances affecting the person receiving it, e.g. pollution does not affect the same way allergic people than healthy young people without respiratory problems.

Currently, most providers of information about air quality are characterized by not supplying this information in real time (minute by minute), not offering information easily accessible to citizens or not providing information customized to the user context (CITEAIR, 2016; Comunidad de Madrid, 2016; CPCB - India, 2014; Department for Environment Food & Rural Affairs - UK, 2016a; EPA - US, 2016b; Government of Canada, 2016a; Travel China Guide - China, 2016). In order to tackle all these challenges, this chapter proposes that the citizens can reach information in a comfortable and easy way, also adapting such information to their particular needs.

To achieve this goal, the Event-Driven Service-Oriented Architecture (ED-SOA or SOA 2.0) defined by the authors in (Boubeta-Puig, Ortiz, & Medina-Bulo, 2015a) is adapted to prevent health risks from air quality by processing data coming from multiple information sources all over the world and notifying alerts to end users in real time when a health risk is detected. Based on the authors' experience in other application domains (Boubeta-Puig, Medina-Bulo, Ortiz, & Fuentes-Landi, 2012; Boubeta-Puig, Ortiz, & Medina-Bulo, 2014a, 2014b; Boubeta-Puig et al., 2015a; Gad, Boubeta-Puig, Kappes, & Medina-Bulo, 2012), they firmly believe that the use of technologies such as Internet of Things (IoT) and Complex Event Processing (CEP) and their integration with SOA 2.0 is key to address such challenges.

The proposed architecture is implemented for the air quality scope. Such implementation is then verified and validated to demonstrate its usefulness in this field of application.

The rest of the chapter is organized as follows. The next section includes background on IoT, SOA, EDA, SOA 2.0 and CEP, as well as related work. The following section overviews the proposed CEP-based SOA 2.0 system for preventing health risks caused by unhealthy air quality. Furthermore, a section that conducts a case study for the detection of unhealthy air quality levels in different geographic areas, is presented. Finally, a section highlights the conclusions and the last section discusses the future work.

BACKGROUND AND RELATED WORK

The subject matters relevant to the scope of this chapter, IoT, SOA, EDA, SOA 2.0 and CEP, as well as related work are introduced in this section.

Internet of Things

IoT establishes that all physical objects can be uniquely identified and represented in the on-line world. IoT can have a high impact on both different aspects of everyday life and behavior of potential users (Atzori, Iera, & Morabito, 2010). According to these authors, some examples of possible scenarios where IoT can be applied are: e-health, home automation, enhanced learning, assisted living, automation and industrial manufacturing, logistics, business/process management, and intelligent transportation of people and goods.

ThingSpeak (ThingSpeak, 2016) is a real-time open data platform for IoT with the capability of managing huge amounts of data per day from thousands of individuals, organizations and companies around the world. This platform provides a RESTful API for manipulating data in JSON, CSV and XML formats. Thanks to its scalable infrastructure, ThingSpeak allows to develop IoT applications, storing, sharing and discovering real-time sensing data and devices all over the world.

Service-Oriented Architecture

SOA is a logical way of designing a software system with the aim of providing services to end user applications or other services distributed in a network, utilizing published and discoverable interfaces (Papazoglou, 2012). According to Chandy and Schulte, any application that implements SOA should meet the following principles (Chandy & Schulte, 2010):

1. **Modular Application:** The application should be modular, so that software components can be added, modified or deleted individually.
2. **Distributed Components:** The components should be able to be run on different computers and communicate with others by sending messages through the network at runtime.
3. **Discoverable Component Interfaces:** These interfaces must be accessible to other application developers. In addition, these interfaces should be defined and clearly documented as metadata. The latter describes the input and output messages of each component, as well as the necessary information to enable developers to find and reuse the component as part of a new application.
4. **Replaceable Components:** A component that provides a service may be replaced by another component offering the same service as long as both share the same interface. This is possible because the design of the interface – what it does – is separated from the service implementation – how it is created.
5. **Shareable and Reusable Components:** The same code and data are available to users of any application that shares the same software component.

Combining the first four principles implies that SOA components are loosely coupled, what facilitates the achievement of the fifth principle. Therefore, this architecture type provides a loosely coupled environment with multiple functionalities, improving the maintenance and evolution of enterprise systems.

Event-Driven Architecture

EDA is a style of architecture in which one or more components in a software system are executed upon receiving event notifications (Etzion & Niblett, 2011). According to Chandy and Schulte, any application that implements EDA should meet the following principles (Chandy & Schulte, 2010):

1. **Event Notification:** Once a new event is detected in the system, it must be notified as soon as possible.
2. **Notification Submission:** The event producer will decide when event notifications should be sent to the event consumer.
3. **Immediate Response:** The event consumer will react, performing some actions, as soon as an event is detected.
4. **One-Way Communication:** The event producer will send event notifications to the event consumer without waiting for any response from the consumer.
5. **Free of Commands:** Event notifications will not contain any action to be carried out by the event consumer after receiving them.

The first three principles refer to the event-driven concept – an entity reacts upon detecting an event, while the last two ones encompass the meaning of minimally coupled – the one-way communication between an event producer and an event consumer in which the producer sends events to the consumer. Note that a system would be event-driven, even though not using an EDA (Chandy & Schulte, 2010). For example, an event producer that sends a notification to an event consumer specifying the particular action to be carried out by the consumer.

These five principles of EDA can be implemented using a publish-subscribe pattern (Faison, 2006; Mühl, Fiege, & Pietzuch, 2006; Taylor, Yochem, Phillips, & Martinez, 2008). By using this type of asynchronous communications, a message can be delivered to zero, one or more consumers without requiring the producer to send it several times. Moreover, a subscription describes the type of messages to be sent to each consumer. It is worthy to mention that the publish-subscribe mechanism is much more flexible than other types of messaging mechanisms because the message delivery instructions can be dynamically defined, thereby subscriptions can be performed at runtime. Another advantage is that new event producers or consumers can be added at any time; likewise, they may be eliminated if so required.

Event-Driven Service-Oriented Architecture

Both previously described types of architectures (SOA and EDA) are not exclusive but complementary, so they can be combined resulting in ED-SOA or SOA 2.0, an evolution of traditional SOA in which communication between users and services occurs by means of events (Luckham, 2012). Any application that implements SOA 2.0 should meet the mentioned SOA principles as well as the EDA ones. To achieve this integration, a middleware is necessary; an Enterprise Service Bus (ESB) is the suitable candidate for this purpose due to its multiple functionalities (Rademakers & Dirksen, 2009): location transparency, transport protocol conversion, message transformation, message routing, message enhancement, security, and monitoring and management.

Despite all the advantages provided by the combination of EDA and SOA, SOA 2.0 is not suitable for processing, analyzing and correlating an enormous amount of information in form of events with the aim of detecting critical or relevant situations in real time. This justifies the need to integrate SOA 2.0 with CEP technology.

Complex Event Processing

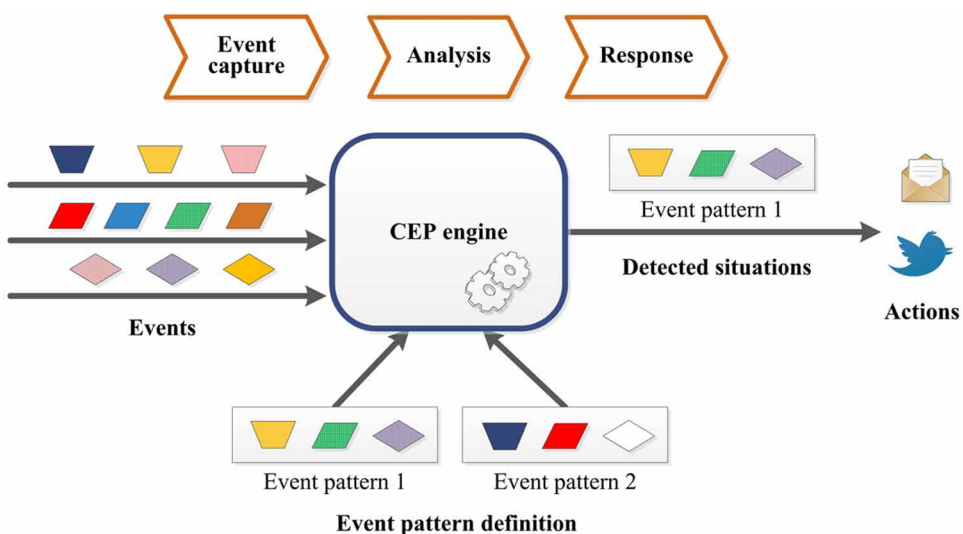
CEP (Luckham, 2012) is an emerging technology that allows us to analyze and correlate huge amounts of data in form of events with the aim of detecting relevant or critical situations (complex events) in real time.

An event can be defined as anything that happens or could happen (Luckham, 2002), but also anything that could happen but does not happen. A situation is an event occurrence or an event sequence that requires an immediate reaction (Etzion & Niblett, 2011). Events can be classified into three main categories: a simple event is indivisible and happens at a point in time, a complex event contains more semantic meaning which summarizes a set of other events, and a derived event is generated when applying a process to one or more other events (Event Processing Technical Society, 2011). Events can be derived from other events by applying or matching event patterns, templates where the conditions describing situations to be detected are specified. A CEP engine is the software used to match these patterns over continuous and heterogeneous event streams (timely ordered sequence of events of multiple types), and to raise alerts about complex events created when detecting such event patterns.

As depicted in Figure 1, CEP is performed in three stages:

- **Event Capture:** It consists of the reception of events to be analyzed by CEP technology.
- **Analysis:** From the event patterns previously defined in the CEP engine, it will process and correlate the information in the form of events in order to detect critical or relevant situations in real time.
- **Response:** After detecting a particular situation, it will be notified to the system, software or device in question.

Figure 1. Complex event processing stages



The main advantage of using CEP to process complex events is that they can be identified and reported in real time, unlike traditional software for event analysis, therefore reducing the latency in decision making. Other relevant advantages are: decision quality improvement, faster and automatic reply, information overload prevention and human workload reduction.

Therefore, CEP is a fundamental technology for applications that:

1. Must produce a fast reply to situations that change quickly and asynchronously and where interactions do not have to be transactional,
2. Must support management by exception,
3. Must quickly react to unusual situation and
4. Require loose coupling and adaptability (Chandy & Schulte, 2010).

Proposals Integrating CEP with EDA, SOA, or SOA 2.0

In order to detect situations of interest in real time, several works integrating CEP technology with EDA, SOA or SOA 2.0 have been proposed over recent years. Table 1 summarizes these proposals indicating the event processing software and middleware used in each case.

Regarding the multiple existent proposals integrating CEP with EDA we would like to highlight that none of them uses an ESB, which would considerably facilitate such integration and would provide additional facilities and advantages, as previously explained.

Concerning the proposals integrating CEP with SOA, all of them describe architectures that differ from our proposal. On the one hand, none of them uses Mule ESB (MuleSoft, 2016), one of the best current ESBs, as maintained by Forrester (Ried, 2014), because of its ability to integrate itself with cloud platforms as well as multiple tools and domain scenarios. On the other, Sottara et al. do not use Esper (EsperTech, 2016), one of the best-known and most widely used open source CEP engines because of its ability to process thousands of events per second and to dynamically manage events in map format – providing greater flexibility when defining event types with nested properties.

Finally, the proposals which combine CEP and SOA 2.0 have some limitations compared to our proposal. On the one hand, none of them has integrated Esper engine with Mule ESB, whose combination would provide the aforementioned benefits. On the other hand, most of these proposals have no graphical editors to help domain experts to define event patterns with their corresponding actions and to transform them into code, what means a major handicap when trying to use the system in a particular domain.

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Table 1. Proposals integrating CEP with EDA, SOA or SOA 2.0

CEP with	Proposal	Topic	Event Processing Software	Middleware
EDA	(Bruns & Dunkel, 2013)	Pattern-based architectures for event processing systems	Own	Own
	(Dunkel, Fernández, Ortiz, & Ossowski, 2011)	Decision support in traffic management systems	Esper	Own
	(Gad, Kappes, Boubeta-Puig, & Medina-Bulo, 2013)	Network analysis and surveillance system based on CEP	Esper	Own
SOA	(Romero et al., 2011)	Smart home environments	Esper	SCA
	(Sottara, Manservigi, Mello, Colombini, & Luccarini, 2009)	Management of waste water treatment plants	Drools	JBoss ESB
	(Zmuda, Psiuk, & Zielinski, 2010)	Dynamic monitoring of SOA execution environments	Esper	ServiceMix ESB
SOA 2.0	(ALERT, 2016)	Coordination among collaborative and distributed virtual teams developing software	ETALIS	Petals ESB
	(Bo, Kun, & Xiaoyi, 2008)	High performance ESB platform for CEP	Own	Own
	(COMPAS, 2011)	Compliance-driven models, languages and architectures for services	Esper	ServiceMix ESB
	(He, Zheng, Xue, & Du, 2008)	Exhaust gas detection services	Own	Own
	(Juric, 2010)	WSDL and BPEL extensions for EDA	Apache ODE	Non-particular ESB
	(Levina & Stantchev, 2009)	Web services-based event-driven SOA	MS Workflow Foundation	.NET framework
	(Ravier, 2010)	Intelligent video surveillance systems	Esper	Own
	(Vidackovic & Weisbecker, 2011)	Methodology for dynamic service compositions	Esper	Open ESB
	(Wieland, Martin, Kopp, & Leymann, 2009)	Method for specification and implementation of applications on a SOA	Esper	BPEL workflows
	(Zang, Fan, & Liu, 2008)	Event processing mechanism in enterprise information systems based on RFID	Own	Own

Air Pollution and Air Quality Monitoring Systems

The World Health Organization (WHO) (WHO, 2016) defines air pollution as *contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere*. The most relevant pollutants of major public health concern are particulate matter (PM_{2.5} and PM₁₀), carbon monoxide (CO), ozone (O₃), nitrogen dioxide (NO₂) and sulfur dioxide (SO₂). Monitoring these pollutants in real time is key because air pollution causes respiratory and other diseases, which can be fatal for human beings.

Nowadays, there are several indexes for reporting air quality, indicating how polluted or clean the air in a particular zone is and what related effects on their health might be a concern for the citizens. However, each index provides details about air pollution levels by using different scales, as summarized in Table 2. For this reason, as an example, air pollution levels measured in the US cannot be compared to those measured in UK. Furthermore, there are different air quality indexes sharing the same scale, which use different value ranges and air pollution levels, as for American and Indian indexes. So far, there is a lack of an international standard that makes air quality measurement universal.

Currently, there are several systems for monitoring air quality levels but only focused in particular areas around the world:

- One of the most well-known systems is EnviroFlash (EPA - US, 2016b), which allows to calculate hourly the Air Quality Index. However, this service only monitors air quality data all over the United States.
- Following a similar structure to EnviroFlash, Europe has also developed its own system, called AirQualityNow (CITEAIR, 2016), to calculate hourly the Common Air Quality Index. Nevertheless, this system only monitors air quality data from cities and regions across Europe. On the other hand, the File Transfer Protocol (FTP) is used to transfer data to this system, not providing web services that would facilitate its integration with third-parties systems or services.
- The government of Canada has also developed a web tool to monitor hourly its own Air Quality Health Index (Government of Canada, 2016b). In order to obtain the air quality level in a particular Canadian location, the end user must click on the map in the region followed by the particular city. Obviously, this is time-consuming and not user-friendly enough. Another limitation is that it does not provide an appropriate interface to be integrated with other systems.

Preventing Health Risks Caused by Unhealthy Air Quality Using a CEP-Based SOA 2.0

Table 2. Several existing air quality indexes

Index Name	Acronym	Zone	Reference	Scale	Range	Air Pollution Level
Air Quality Index	AQI	US	(EPA - US, 2016a)	0 – 500	0 – 50	Good
					51 – 100	Moderate
					101 – 150	Unhealthy for Sensitive Groups
					151 – 200	Unhealthy
					201 – 300	Very Unhealthy
					301 – 500	Hazardous
Indian Air Quality Index	IND-AQI	India	(CPCB - India, 2014)	0 – 500	0 – 50	Good
					51 – 100	Satisfactory
					101 – 200	Moderately-Polluted
					201 – 300	Poor
					301 – 400	Very Poor
					401 – 500	Sever
China Air Quality Index	AQICN	China	(Travel China Guide - China, 2016)	0 – 300+	0 – 50	Excellent
					51 – 100	Good
					101 – 150	Lightly Polluted
					151 – 200	Moderately Polluted
					201 – 300	Heavily Polluted
					300+	Severely Polluted
Common Air Quality Index	CAQI	EU	(CITEAIR - Europe, 2016)	0 – 100+	0 – 25	Very Low
					25 – 50	Low
					50 – 75	Medium
					75 – 100	High
					100+	Very High
Air Quality Health Index	AQHI	Canada	(Government of Canada, 2016a)	0 – 10+	1 – 3	Low Health Risk
					4 – 6	Moderate Health Risk
					7 – 10	High Health Risk
					10+	Very High Health Risk
Daily Air Quality Index	DAQI	UK	(Department for Environment Food & Rural Affairs - UK, 2016a)	1 – 10	1 – 3	Low
					4 – 6	Moderate
					7 – 9	High
					10	Very High

- The Department for Environment Food & Rural Affairs in United Kingdom has also created a web tool called UK-Air (Department for Environment Food & Rural Affairs - UK, 2016b) to monitor air quality in its country. In this case, the air quality information is also accessible via a map not intuitive enough as this information is not automatically updated, being necessary that the user clicks on the specific location.

There are other systems developed by other countries and even by different regions in the same country. Nevertheless, to the best knowledge of the authors, there is no system satisfying the three requirements that the system proposed in this chapter addresses:

1. Information should be available in real time;
2. Information should be accessible in an easy and user-friendly way;
3. The information should be customized depending on the specific circumstances affecting the person receiving it.

ARCHITECTURE FOR PREVENTING HEALTH RISKS RELATED TO AIR QUALITY

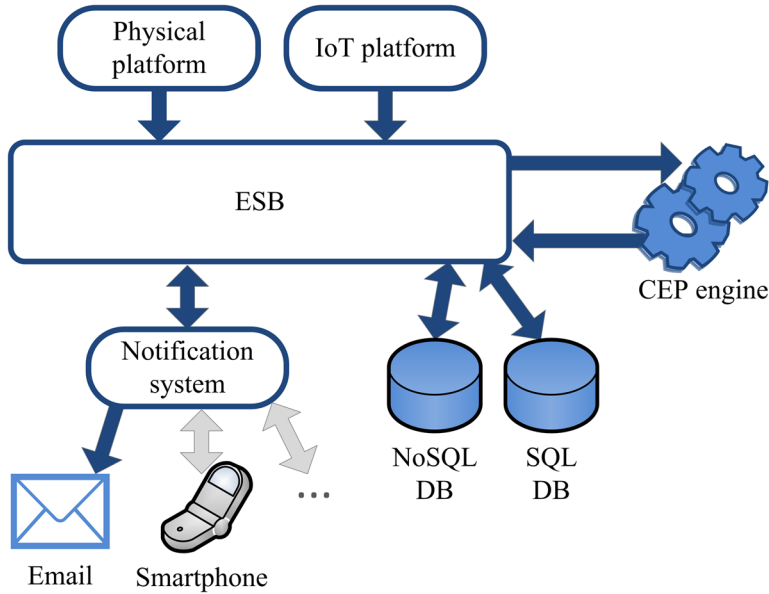
In this section, an architecture system for preventing health risks related to air quality is detailed. Particularly, the main goal of this architecture is to continuously monitor air pollutants with the aim of detecting unhealthy air pollution levels in real time and notifying the interested citizens about them as soon as possible.

In a previous work (Boubeta-Puig et al., 2015a), the authors implemented an architecture for integrating IoT, CEP and SOA 2.0 to ease the efficient detection of relevant and critical situations in SOA scenarios, in particular for a network security domain. Thanks to this architecture, when relevant situations arise from the detection of certain predefined event patterns, real time alerts are sent to the interested parties. In the present chapter, the authors adapt this architecture to support a more complex and ambitious scenario for healthcare, as shown in Figure 2.

The implemented architecture is composed of the following elements:

- **ESB:** The middleware that makes easy the integration of the rest of architecture components, in particular, the connection between event producers and event consumers and the CEP engine.
- **Physical Platform:** It integrates several sensors for monitoring temperature, humidity and air pollutants, such as PM, O₃, CO, SO₂, NO₂ (simulated in the case study).

Figure 2. Architecture for preventing health risks related to air quality



- **IoT Platform:** It provides several services to obtain real-time data coming from sensors located around the world.
- **CEP Engine:** The software with the capability of analyzing and correlating huge amounts of sensing data in form of events and of detecting unhealthy air pollution levels upon pattern detection.
- **Notification System:** Currently the system sends emails to the interested users. We are working on an Android application to be integrated into the system in the near future.
- **NoSQL Database:** It is used to store complex events as well as air quality data coming from physical and IoT platforms. This database type is characterized by not requiring fixed data structures and providing eventual consistency. Moreover, it has the ability to scale horizontally and manage huge amounts of data in a distributed way.
- **SQL Database:** It is currently used to store the emails of the registered users. In our work in progress we are storing additional information about the users. This database type uses fixed structures and provides atomicity, consistency, isolation and persistence; however, it is not suitable for large-scale distributed systems.

The relation between the different components of the architecture is as follows. The ESB is the middleware used for integrating event producers, event consumers and the CEP engine. In particular, it will be in charge of receiving the sensing data from the physical and IoT platforms. Next, this data will be transformed into events following a common format. Then, these events will be sent to the CEP engine, where the event patterns to be detected must be previously deployed, and also be stored into a NoSQL database in order to keep historical data. When the conditions of an event pattern are fulfilled, a complex event summarizing the detected situation is created, stored in a database and sent to the ESB. Once the complex event is received, the ESB will notify it immediately to the registered users by means of the mail service.

CASE STUDY

A case study in the scope of air quality is described and implemented in the following subsections.

Case Study Description

Nowadays, there is great concern about the air quality all over the world since unhealthy air quality levels can affect seriously people's life.

Considering this, several systems have been created during the last decades to provide citizens with the information about what the air quality levels in their living areas are. However, these tools have three main drawbacks:

1. They monitor air quality levels hourly or daily, but not immediately (in seconds or minutes),
2. They only give this information for a particular geographical area or country, but not for everyone, and
3. The notified information is not customized according to the user preferences.

The main aim of this case study is to show that the architecture proposed in this chapter is an effective solution for addressing all these drawbacks, by detecting health concern levels of air quality in real time (minute to minute) all over the world and notifying them to the interested users. The use of this system will allow both health officials to mitigate as soon as possible the impact of the real-time pollution and citizens to take preventive measures to protect their families.

In this case study, event producers consist of simulated sensors located in different zones: Cádiz (Spain), Hamburg (Germany), Tilburg (The Netherlands) and

Montevideo (Uruguay). These sensors, which provide 1-minute measurements of air pollutants (PM, O₃, CO, SO₂, NO₂), temperature and humidity for each location, send this information to an IoT platform. In that way, the information is available all over the world.

On the other hand, event consumers might be:

- **Hospitals:** Health workers would need to know which air quality levels have been identified in each area in order to face the situation, so that to be able to give the suitable advices to protect patient health.
- **WHO and Other International Organizations:** These organizations may subscribe worldwide air quality level notifications to keep themselves informed to be able to establish the corresponding health policies in due time.
- **Citizens:** They will be continuously informed about air quality conditions, for instance in their cities. Therefore, they will be able to follow advices and recommendations to protect their health.

It is important to mention that on this work we have focused on the implementation of the server side architecture that paves the way for future implementation of diverse interested clients.

Data Source Description

A Java simulator has been implemented to generate 1-minute measurements of air pollutants (PM, O₃, CO, SO₂, NO₂) as well as temperature and humidity for four locations around the world: Cádiz (Spain), Hamburg (Germany), Tilburg (The Netherlands) and Montevideo (Uruguay). That is, the sensors in these locations have been simulated.

Moreover, four ThingSpeak channels have been created to send, store and graphically visualize the simulated data in real time. The data update frequency is minute by minute. Particularly, Table 3 summarizes the names and URLs of such channels. Each channel has been structured as shown in Table 4.

The information provided by these channels will be transformed into the event format inside the ESB. This event format is as follows: *AirMeasurement(timestamp, location, pm2_5, pm10, o3, no2, so2, co, temp, humidity)*. Note that *AirMeasurement* is the event type name and the remaining data refers to the event properties.

Air Quality Levels

As explained before, there are several air quality indexes for reporting air quality; however, there is no international standard for air quality measurements. Under this

Table 3. ThingSpeak channels registering air quality data used in the case study

Nº	Channel Name	URL
C1	Air Quality Simulator - Cádiz (Spain)	https://thingspeak.com/channels/59557
C2	Air Quality Simulator - Hamburg (Germany)	https://thingspeak.com/channels/59430
C3	Air Quality Simulator - Tilburg (The Netherlands)	https://thingspeak.com/channels/59558
C4	Air Quality Simulator - Montevideo (Uruguay)	https://thingspeak.com/channels/59560

Table 4. ThingSpeak channels' structure used in the case study

Data	Description
id	Channel identification number
Name	Channel name
description	Channel description
created_at	Channel creation date
updated_at	Channel update date
PM _{2.5}	Particle pollution - 2.5 micrometers (µg/m ³)
PM ₁₀	Particle pollution - 10 micrometers (µg/m ³)
O ₃	Ozone (ppm)
NO ₂	Nitrogen dioxide (ppm)
SO ₂	Sulfur dioxide (ppm)
CO	Carbon monoxide (ppm)
Temp	Temperature (°C)
Humidity	Humidity (%)

scenario, the authors have chosen as reference the American one, called AQI (EPA - US, 2016a), due to its maturity. Nevertheless, this index is currently used only to measure air quality in the US. In the present work, this index will be used to unify real-time air quality measurements made around the world.

Table 5 shows the six air quality levels – Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, and Hazardous – that can be detected. For each air pollutant, it is indicated what the breakpoints that will enable to detect a particular air quality level are. Note that AQI provides two different breakpoints for O₃ (8-hour O₃ and 1-hour O₃); however, only the latter has been taken into account in the table since the sensing data managed in the proposal is frequently updated.

When one of the breakpoints is fulfilled for one location, its corresponding air quality level will be detected. If two or more breakpoints are fulfilled at the same

Table 5. Breakpoints defined by the AQI

Air Quality Level	AQI	O ₃	PM ₁₀	PM _{2.5}	CO	SO ₂	NO ₂
Good	0 – 50	–	0 – 54	0.0 – 15.4	0.0 – 4.4	0.000 – 0.034	–
Moderate	51 – 100	–	55 – 154	15.5 – 40.4	4.5 – 9.4	0.035 – 0.144	–
Unhealthy for Sensitive Groups	101 – 150	0.125 – 0.164	155 – 254	40.5 – 65.4	9.5 – 12.4	0.145 – 0.224	–
Unhealthy	151 – 200	0.165 – 0.204	255 – 354	65.5 – 150.4	12.5 – 15.4	0.225 – 0.304	–
Very Unhealthy	201 – 300	0.205 – 0.404	355 – 424	150.5 – 250.4	15.5 – 30.4	0.305 – 0.604	0.65 – 1.24
Hazardous	301 – 500	0.405 – 0.604	425 – 604	250.5 – 500.4	30.5 – 50.4	0.605 – 1.004	1.25 – 2.04

time, the air quality level will be defined as the most dangerous one for that location. For instance, having a PM_{2.5} value of 40.9 µg/m³ and a CO value of 8.4 ppm implies the detection of the following air quality levels: Unhealthy for Sensitive Groups and Moderate, respectively. Since the Unhealthy for Sensitive Groups level is more dangerous than the Moderate one, the global air quality level for this location will be Unhealthy for Sensitive Groups.

Event Patterns for Air Quality Levels

In the following paragraphs, the event patterns necessary to detect air quality levels are described and implemented in Esper EPL (Event Processing Language) (EsperTech, 2016): a declarative language provided by Esper CEP engine.

Eight event patterns have been proposed with the aim of detecting relevant air quality levels for citizens: *GoodAirQuality*, *ModerateAirQuality*, *UnhealthyForSensitiveGroupsAirQuality*, *UnhealthyAirQuality*, *VeryUnhealthyAirQuality*, *HazardousAirQuality*, *AirQualityLevelByLocation* and *AirQualityAlert*.

The first six patterns, which are in charge of detecting the air quality levels around the world, have been defined according to the breakpoints defined by the AQI, which are shown in Table 5. As an example, Listing 1 shows the implementation of the *ModerateAirQuality* event pattern. First of all, the event pattern is specified by making use of the *from pattern* clause. Next, all *AirMeasurement* events fulfilling the conditions are selected by using the *every* pattern operator. In order to refer these events later, it is necessary to assign them an alias (in this case, *a1*). Finally, the properties to be selected from the events matching the pattern conditions are specified. These properties are: the air quality level number, the level name, the timestamp, the

Listing 1. Esper EPL implementation for the ModerateAirQuality event pattern

```
@Name('ModerateAirQuality')
insert into AirQualityLevel
select 1 as levelNumber,
'ModerateAirQuality' as levelName,
a1.timestamp as timestamp,
a1.location as location,
a1.pm2_5 as pm2_5,
a1.pm10 as pm10,
a1.o3 as o3,
a1.no2 as no2,
a1.so2 as so2,
a1.co as co
from pattern [(every a1 = AirMeasurement(((a1.pm2_5 >= 15.5 and
a1.pm2_5 <= 40.4) or (a1.pm10 >= 55 and a1.pm10 <= 154) or (a1.
so2 >= 0.035 and a1.so2 <= 0.144) or (a1.co >= 4.5 and a1.co <=
9.4)))))]
```

location and all air pollutant values. The *insert into* clause specifies that this pattern will create a new complex event with such properties: *AirQualityLevel(levelNumber, levelName, timestamp, location, pm2_5, pm10, o3, no2, so2, co)*. Note that the air quality levels have been enumerated from the healthiest level as 0 (*GoodAirQuality*) until the most hazardous one as 5 (*HazardousAirQuality*).

So far, the described event patterns allow the detection of air quality levels according to each air pollutant value around the world. As mentioned before, if different air quality levels for the same location in a specific point in time are detected, the global air quality level will be defined as the most dangerous one in that location. In order to deal with this requirement, the *AirQualityLevelByLocation* event pattern has been implemented as shown in Listing 2. A tumbling time window, which batches *AirQualityLevel* complex events and releases them every 5 minutes, has been included in this pattern. These complex events inside the windows are grouped by location for which the maximum of their air quality level numbers is calculated. Then, this maximum is included in the new complex event called *AirQualityLevelByLocation*, indicating the global air quality level per location.

Since citizens are interested in being notified when the air quality level is not appropriate for their health, another event pattern has been implemented – see Listing 3 – to create a new *AirQualityAlert* complex event upon the detection of an *AirQualityLevelByLocation* complex event, whose air quality level number is

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Listing 2. Esper EPL implementation for the AirQualityLevelByLocation event pattern

```
@Name('AirQualityLevelByLocation')
insert into AirQualityLevelByLocation
select max(al.levelNumber) as levelNumber,
al.location as location,
current_timestamp() as timestamp
from AirQualityLevel.win:time_batch(5 min) as al
group by al.location
```

Listing 3. Esper EPL implementation for the AirQualityAlert event pattern

```
@Name('AirQualityAlert')
insert into AirQualityAlert
select al.*
from pattern [every al = AirQualityLevelByLocation(levelNumber
> 0)]
```

greater than 0. In other words, the level is expected to be moderate, unhealthy for sensitive groups, unhealthy, very unhealthy or hazardous.

Event Patterns Verification

The authors have already developed MEdit4CEP (Boubeta-Puig et al., 2015a), a model-driven solution for real-time decision making in SOA 2.0. Its main aim is to make domain experts' tasks of defining both event patterns – situations of interest to be detected – and alerts for real time notification easier, hiding all implementation details from them. More specifically, it provides an editor for facilitating user-friendly design of event patterns for different domains as well as for automatically transforming them into code. This editor is independent of both the domain where CEP technology is needed to be applied to, and the particular EPL required by a particular CEP engine. Notice that the domain-specific modeling languages required as the basis for event pattern editor's creation was published in (Boubeta-Puig, Ortiz, & Medina-Bulo, 2015b).

In order to verify the right EPL implementation of the event patterns for air quality levels, we have asked an expert on air quality to define them using the graphical editor MEdit4CEP and doubled checked the correctness of the implementing code, compared to the generated one.

As an example, Figure 3 illustrates the result of modeling the *ModerateAirQuality* event pattern with MEdit4CEP. This graphical pattern can be read as follows: every *AirMeasurement* event, which fulfills the conditions established by AQI for the moderate air level – conditions designed on the figure’s left side, will create a new complex event called *AirQualityLevel* containing the air quality level number (1), the level name (*ModerateAirQuality*), the timestamp, the location and all air pollutant values.

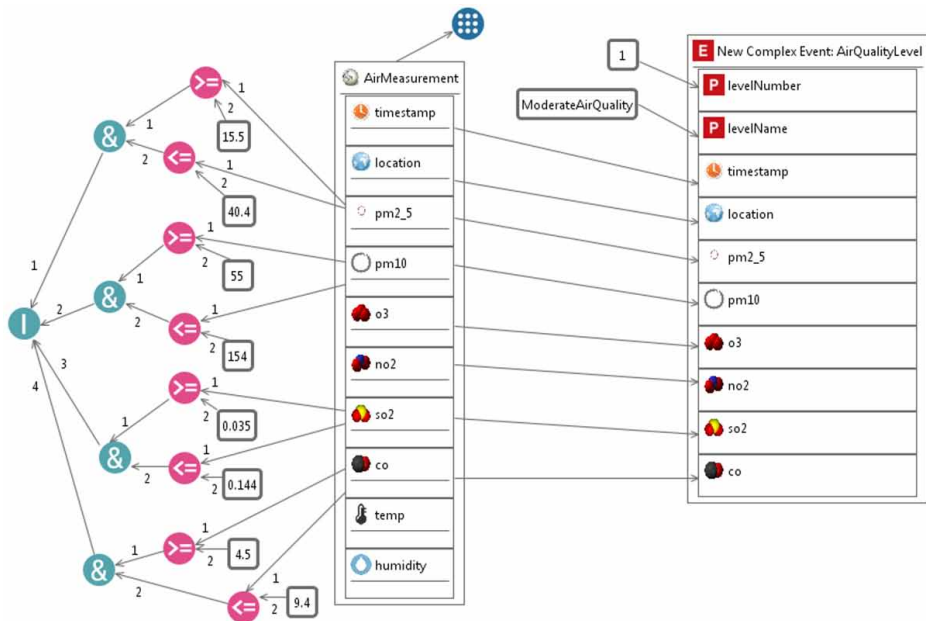
As a result, we can assure that the event patterns code generated by MEdit4CEP is the same as the one given on Listings 1-3.

Architecture Validation

The authors have adapted the implementation of their architecture that combines CEP, IoT and SOA 2.0 in order to detect different levels of air quality in real time. In particular, the following technologies and frameworks have been used: Mule (MuleSoft, 2016) as ESB, Java as programming language for creating the data simulator, ThingSpeak (ThingSpeak, 2016) as IoT platform, and Esper (EsperTech, 2016) as CEP engine.

The system implementation has been tested during two weeks (October 8th – 22nd, 2015). An example of the data simulated for Cádiz city can be seen in Figure 4. Due

Figure 3. *ModerateAirQuality* event pattern graphically modelled using MEdit4CEP

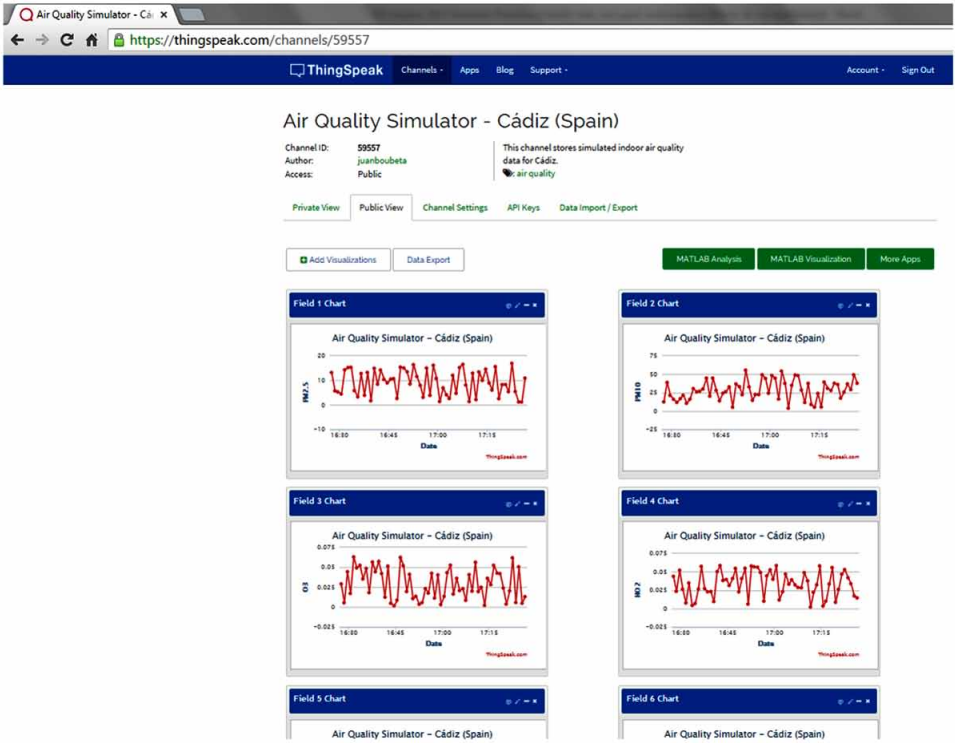


to the fact that air pollutant values have been randomly generated by the simulator, it does not make sense to deeply analyze in this chapter when and how many event patterns have been detected by location. Nevertheless, the authors have checked that the implemented system is capable of minute by minute detecting the different air quality levels for the proposed locations in the case study – Cádiz, Hamburg, Tilburg and Montevideo – and it correctly notifies them to the interested users. It is noteworthy to mention that the system is easily scalable since new ThingSpeak channels or even physical sensor platforms can be easily integrated by means of the ESB.

CONCLUSION

An architecture system has been proposed for preventing health risks related to air quality by integrating IoT, CEP and SOA 2.0. Thanks to this architecture, when relevant situations arise from the detection of certain predefined air quality event patterns, real-time alerts will be sent to the interested parties.

Figure 4. ThingSpeak channel that manages simulated air quality data for Cádiz (Spain)



A case study illustrating this approach has also been described and implemented. In particular, several simulated sensors have been made available through ThingSpeak – a real-time data infrastructure platform for the IoT – and have been used as event producers. The raw data generated by these producers are published into a Mule ESB application, which transforms this data into events and then sends them to Esper. This CEP engine will be able to detect complex events that specify a particular level of air quality or a change in this level in a location at a point in time. When an unhealthy air quality level is detected for a particular group of users, then a notification will be sent to the interested event consumers.

Therefore, this system can detect current air quality levels in real time (minute by minute), ensuring the prevention of health risks; in contrast to current tools that report these situations hourly or daily, or even as historical data to be downloaded in CSV on demand.

Furthermore, this system can be easily adapted to different domains; although the air quality has been chosen as application domain in this chapter; once new event patterns are defined, the system could be used for the prevention of a variety of diseases as well as for nonmedical fields, should it be necessary. The integration of ThingSpeak and Esper, making use of Mule ESB, allows the CEP engine to process real events shared per day by thousands of individuals, organizations and companies all over the world.

FUTURE RESEARCH DIRECTIONS

Concerning the future work, the implemented system will be completed with the integration of other event producers and event consumers. These producers and consumers will be easily integrated into the system thanks to the ESB, which helps to increase the flexibility of heterogeneous environments.

A physical sensor platform is necessary as event producer to manage real sensing data, instead of simulated. The authors are currently working with the Gases Sensor Board for Waspote (Libelium, 2016), which is Libelium's advanced mote for wireless sensor networks. This board enables technical users to implement pollution and air quality systems with high requirements in terms of high accuracy, reliability and measurement range since the sensors come accurate calibrated from factory.

Regarding event consumers, we are working on two main future lines:

- Since citizens play an important role in this health scenario, the authors have planned the development of a specific mobile application that can be installed on their smart phones in an easy and intuitive way. Therefore, they will be immediately notified when an air quality level undesirable for their health is

detected. When installing the application, or later, they will be able to register themselves on the application to receive notifications of air quality levels unhealthy for them. Users not registered on the system will only receive general notifications based on which air quality levels, the WHO and other health organizations, such as US Environmental Protection Agency (EPA), consider dangerous for an adult without relevant diseases, regarding heart and respiratory systems. If the users also provided personal information (age, cardio-respiratory diseases, allergies, etc.) then the notifications will be customized for their particular risk group.

Obviously, regardless of notifications, citizens will be able to access to current information about air quality levels at any time. Besides, notifications are expected to be received in a graphical and user-friendly way, for example, visualizing the information on customized Google maps. We also expect to make the air quality levels and alerts available through a website.

- Additionally, actuators could be integrated into the system as their use will be clearly a benefit because some mechanical actions would be taken when detecting specific complex event pattern. For instance, turning on a humidifier if the humidity has been considerably reduced in a particular home.

Making this prototype capable of anticipating critical health situations before they appear is another research direction. That way, the system will not work in a reactive way but a proactive one, taking precautions to protect citizens in advance.

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KEY TERMS AND DEFINITIONS

Air Quality Index: A tool for reporting air quality, indicating how polluted or clean the air in a particular zone is and what related health effects might be a concern for the citizen.

Complex Event: An event that contains more semantic meaning, by summarizing a set of other events.

Complex Event Processing: A cutting-edge technology that allows for the analysis and correlation of large volumes of data with the aim of detecting complex and meaningful events and of inferring valuable knowledge for end users.

Enterprise Service Bus: A software architecture model used to facilitate interaction and communication between service-oriented applications.

Event: Anything that happens or could happen.

Event-Driven Architecture: A software architecture type that reacts to multiple events under several conditions.

Event Pattern: A template that defines the conditions for detecting situations of interest in real time.

Event Processing Language: A language type for defining event patterns.

Service-Oriented Architecture: A software architecture type, based on services.

Web Service: A modular application that can be invoked through the Internet following some established standards.

Chapter 7

The Role of Time in Health IoT

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ABSTRACT

As the biological processes in the body change constantly, comparable measurements should be taken simultaneously in time and place. In practice, this is hard to achieve. Synchronicity is required to certify medical accuracy for a new device by reference to a certified one. In a typical health IoT, synchronicity cannot be enforced procedurally and timing needs to be part of the network architecture. Popular examples are in blood pressure measurement. Putting the blood flow in a known pinch-off situation performs synchronization. But this principle cannot be extended to other non-invasive measurements. Hence the chapter proposes to synchronize on basis of the heart rate extracted from the blood flow at arbitrary positions on the body. This models the blood flow in the body and relates all to the rhythm of the heart. It brings existing phenomena into a single, multi-level model that allows wireless networked wearables into a single health-monitoring scheme.

INTRODUCTION

The physical effect of sound propagation is rumoured to have decided the Olympic gold medal for 500 metres speed skating in Sochi 2014. The start of the race is sounded by a shot as part of a ceremony that brings the racers to attention. The competition has become very challenging over the past decades. Nowadays differ-

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ences of milliseconds determine to have gold or nothing. Smeets and Mulder made such a race, but it was shown afterwards that the real difference, being everything else equal, was made by the starting position on the arena. The person closer to the centre hears the shot slightly sooner. Such an advantage can easily decide the championship when the run itself is short also.

The phenomenon is not rare. In the eighties, the on-going miniaturization has cast attention to the different scaling of the clock and the logic signals. Clocks are passed over different paths on the distribution network and will therefore be delayed differently. Then time can be different where after following different paths the same clock is logically exerted. The remedy has been to divide the chip area into iso-chronic areas, parts where the differences in time definition is still negligibly small. Communication between such parts will be by more elaborate, clock-less mechanisms. This is called globally asynchronous, locally synchronous or GALS communication (Spaanenburg, 1987).

These are only two of the many situations where two observations have problems to be synchronized. A new branch of the tree is mHealth. The heart takes the role of the atomic clock for the human body. It pumps the blood around to distribute the clock event to the organs. The heart rate is not a known and constant value but can be reasonably determined invasively; however the determination of the exact timing will be harder to achieve.

In this chapter the role of timing in the overall discussion on blood flow analysis is looked at. Then we step up the involvement of timing within the extraction of blood pressure (BP). From there the attention is broadened to networked collections of health devices. In the end we extend the issues to system reliability, the main requirement to any product in the health sector.

BLOOD FLOW ANALYSIS

Deep down, the heart drives the blood circulation system. However, its main pipe has a flexible wall and hence behaves non-linearly in response to the applied pressure. The transients in the heartbeat will gradually be smoothed while passing through the artery. Everywhere in the blood circulation system, the heartbeat can be found in a related but gradually different way. Ultimo, some non-invasive measurements at spread-out locations can be used to model an invasive measurement at the heart.

Circulation Diagnosis

Electrocardiogram (ECG) measurements need proper placement of a number of probes. If accurately executed, the signal can be detailed enough allowing more

than 250 heart diseases to be detected by the trained nurse. The operation is costly and limited in use to special situations. For the early detection of heart failure, the procedure needs to be cheap and casual.

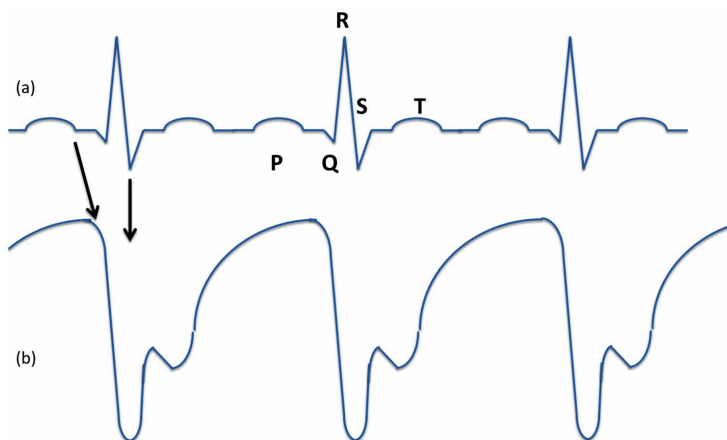
The heart signal is an intricate set of positive and negative pulses with intermediate planes: the PQRST complex (Figure 1a). It shows the ventricular activity and can be measured as electrical signals. As every peak and every plane has a functional meaning, any aberration has consequences. Though such deviations may be meaningful, they are not appearing often, if ever. Usually a Holter device needs to be carried for one or more days to catch a glimpse of the heart failure. With heart failure being a major cause of sudden death, a cheap and casual detection without special installations is required.

A healthy body is one in which the heart has no problems to bring blood to all parts of the body. Classical medicine targets the organs, but the body is much more. For instance, an early sign of diabetes is lack of blood flow in the toes. So general health needs to capture both the quality of the heart, usually read from ECG analysis, as well as the service ability of the blood circulation system, potentially found from a distributed Photoplethysmography (PPG) application.

Flow Quantification

Blood flows through the arteries under the periodically changing pressure as applied by the heart. The wall of the artery is flexible. It opens up when the pressure is building up and narrows again afterwards. Hence the local blood volume varies in symphony with the heart pulse. This changing blood volume becomes visible in

Figure 1. The (a) PQRST vs. (b) PPG relationship
Source: Al-Qazzaz, 2014.



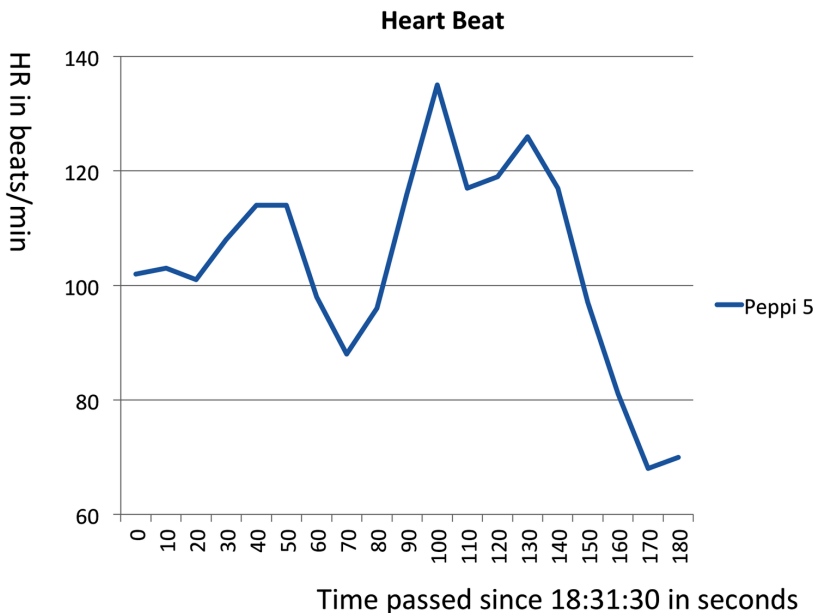
the reflected light that is penetrating the skin. The intensity of the reflected light is called the Photoplethysmographic or PPG signal (Figure 1b).

Both PQRST and PPG source from the same heart process. They are likely to have many commonalities but there is a lot of variance in the details. The major difference is that the PPG signal is a derivate (and therefore slightly delayed) but can be casually and non-invasively extracted. Therefore the usual heart rate monitoring wearables work from the PPG signal.

The vision-based PPG extraction is sampled at a low rate. The sampling error is already 5% if the cardiac cycle takes 20 frames. If the cardiac cycle is constant, the sampling error is drastically improved by having two or more sensors close to one another as has been done in the i-watch. By averaging over many cycles, the accuracy will improve further if sampling gives an evenly distributed error. Unfortunately longer observation series bring also handling, temperature and motion related noise. But the main issue is that the cardiac cycle is not constant. Hence heart rate is a momentary value that can only be extracted from small shots (Figure 2).

The most flexible is therefore the Short-Shot Heart Rate Monitor (SSHRM). It measures a series of heart rate values from short shots seen from sliding windows. This allows to see the dynamics of the body. In the last section, this will also be used in creating dynamic synchronization between health devices.

Figure 2. The drift of a ‘stable’ heart rate (AMS watch)



Synchronization in Space

The alternative to measuring the signal propagation between two known positions is to measure the signal on a single position at two known times. Then the issue is to define the unit of time. The sensor defines the sampling period, which will be related to frame rate in case of a vision sensor. However this unit of timing is not directly related to the heart rate, the fundamental timing notion inside the body. Therefore the timing definition of the heart rate in terms of frame rate is important.

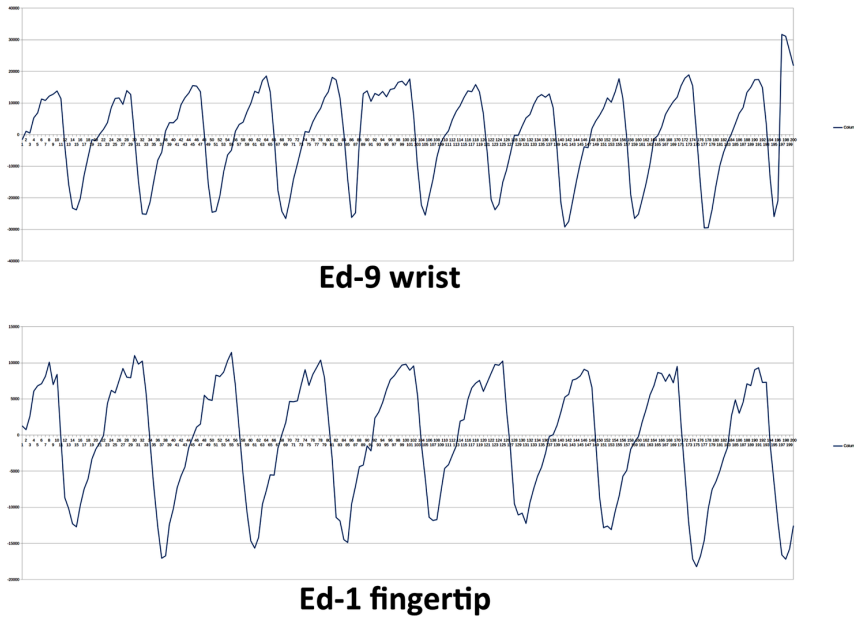
Most of the heart rate monitors (HRM) determine the signal periodicity by measuring the peak-to-peak distances in the time domain (Watson, 2015). As the slightly fluctuating process (Heart Rate Variance or HRV) is coarsely sampled, the trick is to take a larger period and average the period values. Similarly, power spectrum analysis in the frequency domain shows the heart rate by the main energy peak. Such methods do not provide any indication of the exact location. This seems to be another occurrence of the Heisenberg uncertainty principle. Apparently our investigation has to be done in the time domain, not the frequency domain.

The interest in heart monitoring is in finding potential heart failure. But fitness comes on a good 2nd place. Fitness criteria like the “Cooper test” are based on oxygen saturation in combination to heart rate (Cooper, 1969). This is perfectly ok for becoming the sporty person, but regularly it shows that this is still no guarantee for a sound body. The long-term goal has remained therefore the non-invasive measurement on the heart itself. At the core of this problem is the isolation of the ‘clock’: the significant effect tightly related to ECG and PPG that times all other effects in the body.

In a simplistic 1st order approximation, the ideal PPG signal controlling the blood flow can be modelled as a step-wise input to a transmission line system. However the signal is dispersed on monitoring and the actual moment of the step-wave on the input becomes less transparent. This leaves the question how to reconstruct it. In (Klofutar, 1993) it was shown that a non-linear model is required to handle such an n^{th} -order differential equation. A very structured way to perform non-linear filtering is performed by a classic tapped-delay feed-forward neural network with specific training for the wrist or the fingertip (Figure 3).

Both the PQRS complex and the PPG signal have a significant peak that can be used to identify the separate cardiac cycles (Kuntamalla, 2014). The R-to-R distance is commonly used in the PQRS complex, while the distance between the systolic peaks is used in the PPG signal. These peaks are related but do not come at the same moment. The relation is important, as parameters such as blood pressure can only be computed from the defined start of the cardiac cycle. When the signal dispersion makes the individual peaks hard to see, such synchronization peaks require additional attention as small errors lead to large errors in the blood pressure calculation.

Figure 3. Filtering a diffused PPG signal



BLOOD PRESSURE

The system is based on the collaboration of an occasional ECG device and a regular BP monitor. Both devices synchronize on the R-peak of the heart signal. The heart signal is cyclic where the overall blood circulation takes typically 6-8 heart cycles. A second level of synchronization between ECG device and BP monitor is to identify how many cycles are passed between the respective measurements using these devices. A third level involves the matching between particular features in the current ECG signal and past features in the PPG analysis.

Blood Pressure Measurement

Is the light in the refrigerator really off? While the door is open, you can still see the light in there. When you are closing the door, the light is visible to the last. So, how can you know? A window would help, but it is usually not part of such a product. Let's take a different example.

The situation seems easier with single lane road reconstruction. Each time the traffic can flow in one direction, while the cars at the other side are waiting their turn. Changing the direction starts with stopping both directions till the site is empty and then the other side can flow. If the reconstruction site is small, visual

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monitoring is sufficient to determine whether it has been totally emptied. If it is large or when obstacles block the view, information has to be collected from both sides to determine:

1. If both sides are currently closed, and
2. If all (or the last one) has reached the other side.

Practice gives a value for the expected time to wait for clearing the traffic.

Blood pressure measurement goes along the same ways. The principle starts by applying a cuff on the upper-arm and pressurize it till the blood flow stops. Whether the blood flow stops can be heard on the lower-arm. Then the cuff is slowly deflated till the blood can be heard again. The blood pressure can be found from the applied cuff pressure. The alternative uses slight pressure differences applied through the cuff, and measuring the time delay after these nuances become noticeable at the lower-arm. All such methods cannot be used at arbitrary body locations nor in a casual manner. They require appreciable skill to be used correctly.

Basic Calculation

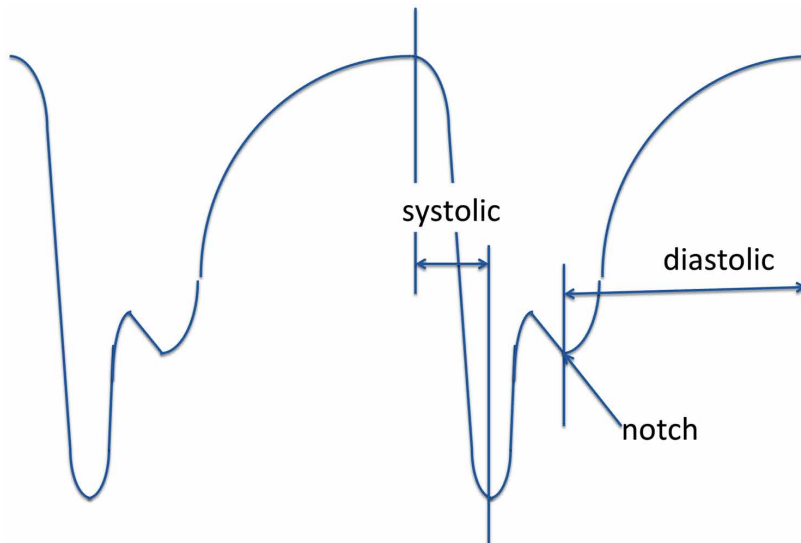
The interpretation of a PPG signal starts from the determination of top and bottom. The signal fluctuates but the meaning of top and bottom are dependent of the measurement method. The systolic region is the one with the steepest flank. For the basic signal, the start is a well-defined extreme and the time elapse to cross the distance from top to bottom (or vice versa) relates directly to the systolic blood pressure. Clearly, a less-defined beginning will result immediately to an appreciably large measurement error (Figure 4).

The diastolic region is the second half of the cardiac cycle and starts from the end of the systolic one. As it is longer, the definition of the beginning and the end is less important. Somewhat in the middle one finds the “dicrotic notch”. It is found that the distance between the dicrotic notch and the onset of the systolic region is directly related to the diastolic blood pressure. Unfortunately, the location of the notch is one of the first signal details that appear in the dispersion.

The further the signal comes in the transmission line, the more the signal becomes susceptible to a number of environmental noise source. Doing the operations on PPG data in the time domain allows qualification of the signal shapes. Such shapes are characteristic for the differences measured at different locations. This helps to extract the position models as well as to disqualify cycle for specific analysis purposes.

Figure 4. Blood pressure parameters on the basic PPG signal

Source: Yoon, 2009.



Compensation for Dispersion

Blood pressure refers to the force exerted by circulating blood on the walls of blood vessels and constitutes one of the principal vital signs. The systolic pressure is the peak pressure in the arteries, which occurs near the beginning of the cardiac cycle. The diastolic pressure is the lowest pressure, which is at the resting phase of the cardiac cycle. The average pressure throughout the cardiac cycle is reported as the mean arterial pressure. The pulse pressure reflects the difference between the maximum and minimum pressures measured.

The product supports the identification of potential early heart failure in two ways. Firstly, the BP monitor has learned which of the PPG characteristics can be identified with ECG abnormalities. Vice versa, the ECG device has learned which of the PPG characteristics can be identified with incomplete circulation phenomena. Both devices can be trained to identify potential issues but will only in combination become medically reliable. Thus the commercial casual monitor will already be indicative and support a later professional application.

HEALTH THINGS

The smart phone being a computer with sensors indicates that in principle a single object can handle all health parameter extraction. In practice, it is hard to compromise the requirements for the various extraction methods. A thimble can be used to draw a drop of blood for glucose measurement; a set-up lens can support infrared vision. This has drawn attention to medical support hardware that can be worn on (or inserted into) the body and performs as much as possible of the required functionality. A typical insulin unit measures glucose and delivers insulin (vanDijk, 2014). Largely for safety reasons, an external phone reads the measured values and eventually writes commands for insulin control.

In some way, the wearable/phone interaction is the smallest imaginable network. Such two parts are necessary but not necessarily sufficient. Sensors can be heavily specialized; the placement can be at different body locations; the body status changes continuously. For all such reasons, there are many network arrangement in time and place. A number of significant network arrangements will be discussed in the following.

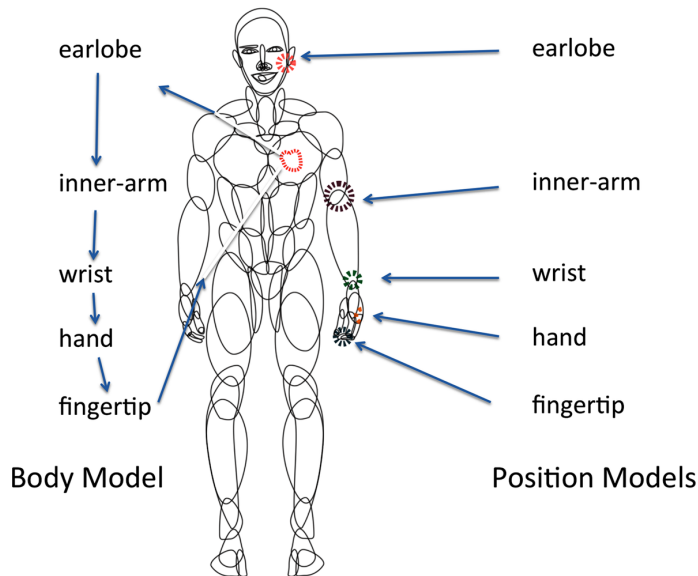
Single Device, Distinct Times

Continuous heart observation is crucial for the prediction of heart failure. However, the lack of direct access makes products such as a Holter device the best alternative. It has been shown that focussed light can reach the arteries and measure the geometry (Borgos, 2012). Parameters like blood pressure can then be quantified from the continuous changes in artery geometry.

The basic measurement principle is that all external observations can be referenced to a single ‘gold pot’, the medically verifiable measurement at a medically monitored location. We call this ‘the lab’ and refer to those data as ‘the lab values’. This builds a relation between each measurement and its reference, called the ‘position model’.

Where the measurements on various positions have a position model, their relation to the single ‘gold pot’ can be drawn in a star model (Figure 5 right). In principle an arbitrary number of stars can be modelled. By star/ring conversion, the individual position models can be turned into an overall ‘body model’ (Figure 5 left). This relates the measurements on various positions according to the physical blood flow. More modelled positions brings more accuracy. But also the converse is true: when sufficient positions are modelled, an occasional missing or faulty value can easily be bridged.

Figure 5. Star and ring modeling configurations



Multiple Device, Single Time

It is important for the verification of a new measurement method that it is not only compared with a lab value but also that both measurements happen at the same time and at the same location. This is hard to accomplish. It is much easier to collect a series of data simultaneously, followed by correlation of the series to find a suitable mapping in time.

Multiple devices will also appear in fashion or in plaster-based belts in an integrated way (Spaenburg, 2016). There are plasters with unique sensors and glued wires to give the overall functionality, especially in the fitness market. There are similar trends in the fashion market, but overall more experimental. Anouk Wipprecht is the rising star in couture (Cass, 2016). The offering in the catalogue arena is steadily increasing (Wearable Technologies, 2015).

The main issue with this arrangement is to guarantee the synchronicity. The measurements must be taken at the same time, even though it will not be at the same location. Additional steps may be required to bring the results out. This comes close to the requirements of the BioPhone (Hernandez, 2015).

Redundant Devices, Some Time

The various measurement techniques have all their individual shortcomings. When a doctor applies a device, he should know about the limitations or at least he should doubt the result. The famous Nobel laureate Heike Kamerlingh Onnes preached “From data to knowledge” (a free translation from the Dutch “Door meten tot weten”). The attached warning is of course that incomplete data will easily lead to nonsense.

Heart rate monitoring seems transparent. However, with age more and more people have fibrillation (Carroll, 2001). It is a comparatively small signal at harmonics of the heart frequency.

In August 2015, I went for a check-up in the hospital. In a hurry the nurse applied the usual sphygmomanometer and I almost died of pain. The meter shows a ridiculous high value. I complained in telling that the reading will be wrong, but she wrote the numbers down and rushed off. During the consult, the heart surgeon said that the sphygmomanometer is old and occasionally fails. As a comfort, he said, the EKG looks ok and that is all that matters!!

Apparently data collection outside the realm of the medical profession is a point of concern.

Redundancy helps to establish a correct value, but multiple sources for data do not necessarily create for redundancy. In a typical IT infrastructure for health services, data are keyed in without taking the data origin into account. Consequently there is no guarantee on the data quality in the electronic health dossier when access by arbitrary persons with arbitrary devices is permitted. Where such big databases are in vogue for performing statistical operations to extract new and unknown relations, misleading conclusions will be produced. The only reasonable work-around is shown in the daily practice of astronomy: every meaningful discovery needs to be confirmed independently. One may see this as a kind of procedural redundancy.

TOLERANCE

Health can be endangered when one or more sensors are not functioning correctly. Such erroneous behaviour should be detected and consequently either by-passed or compensated. Preferably the system continues to provide meaningful information and creates the time for a timely repair. Ultimately, the system should clearly indicate the problem and refuse to give false information. It would rather die!

Health is a clear application of system reliability (Spaanenburg, 2010). The most successful means to reliability is hardware redundancy. The idea is that errors

come individually and majority voting will easily decide on the truth. Unfortunately, practice is hard and fabrication sensitivities break the theoretical effectiveness. The cases where hardware multiplicity is applied to achieve majority voting are usually where accidents are costly. Health should be 100% fault-tolerant because losing health is costly. In the following we look at the different levels where redundancy can be applied to raise the reliability level.

Data Reliability

The common practice in data reliability is by averaging. Small variations will easily peter out but outliers have a large influence. A number of methods can be used to eliminate the influence of outliers, largely based on some degree of clustering. In some heart monitor devices, it is assumed that the rate will change only slowly in static situations. This can be used to filter large variations away.

The alternative is to cluster the cardiac cycle durations. This keeps heart rate variance still in view. Further the signal shapes are categorized, allowing to qualify the results in terms of model adherence. The qualification indicates which cycles are apt for blood pressure calculation taking the positional model into account. Hence the derived results, such as blood pressure and oxygen saturation, can be graded for reliability.

The connected benefit of the cycle-based qualification is that it allows taking some dynamics of the heart rate into account eventually. Within a typical observation period, we find a heart rate change from 60 to 90 beats per minute. Averaging the values over the entire period is hardly meaningful and will definitely lead to errors in the blood pressure calculation. The data are much more reliable when clustered over a quasi-static interval. This stresses again for the use of a Short-Shot Heart Rate Monitor.

Tic2Go

Pulse Wave Transfer can be implemented on a brace, such that the stimulation and the sensing parts are positioned at a known difference. This trick can hardly be extended without turning the brace into a rigid body harness. The alternative is to have multiple devices that measure the wireless signal transport distance automatically, such that multiple control pulses can be transmitted to act at the different location at the same moment. This brings the collection of position models into a single body model, all around the single event called the heartbeat.

In software, a popular pattern called the Event-Driven Architecture (EDA) promotes the production, detection, consumption of, and reaction to events. This can be defined as “a significant change in state” (Mani, 2006). For example, when

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a person waits at the bus stop, his status changes to passenger when getting on the bus. The public transport system may sense this state change as an event whose occurrence can be made known to the accounting part within the architecture. From a formal perspective, the simple act of swiping the ID-card for access is a (typically asynchronous) message called the event notification, and not the event itself, which is the state change that triggered the message emission. Events do not travel, they just occur.

This software pattern may be applied for the implementation of networks comprising of loosely coupled nodal elements. The overall event-driven system is constructed from event producers (sources or agents), event consumers (sinks or acceptor) and event channels. Producers will detect, identify and pass specific features, such as the start of a cardiac cycle by the onset of the systolic region. Such events are detected without any awareness of the presence, existence or nature of a consumer. It does not even know whether the event will be processed or continued.

A consumer gets into action when receiving an event to produce a reaction either in full or in (partial) preparation (for instance by filtering or transformation) for another node to complete the action. Event channels are the mechanisms to move events from producers to consumers. The network topology, the distribution mechanism and eventual buffering is only known to the event channel. There is a wide variety of physical implementations for event channels. A growing amount is based on the Internet. In the consumer sector it is usually shaped as Internet of Things (IoT), in the industrial sector the need for real-time performance is added to achieve Industrial Internet.

The Time-Triggered Architecture (TTA) is a computer system that executes one or more sets of tasks according to a pre-determined task schedule (Pont, 2001). The TTA can be seen as a special case of the EDA. A typical Time-Triggered system is based on a single interrupt, which in our case is the start of the systolic region. In the body model, this interrupt drives the task scheduler and so releases the system tasks at predetermined points in time. The popularity of the Time-Triggered system is that the real-time software can easily be demonstrated to be correct: a major benefit for software in the health sector.

The Body Is the Network

The human body is largely a closed system. When substances leak in an unexpected manner, this gives reason to assume that something is going wrong. That is especially true for the blood circulation. Hence the accuracy of the ring model can be enhanced by demanding that the ring is in fact an infinite string.

The model is synchronized into cardiac cycles. The full blood circulation needs to be an integer times of cardiac cycles, or, again, there will be a health issue (Campbell, 1994). The closure condition needs the posture of the person into account as it influences blood pressure. Such effects give a further complication of the body model. Current technology is largely restricted to static measurements, a situation whereby the person is fully at rest.

CONCLUSION

The design and development of mHealth device can be easily complicated when not taking their role as part of a collective health monitoring system. The need to fit in the data architecture of the Health Internet of Things poses demands that can best be accommodated when considered early on in the algorithm selection. Particularly we show this in explanations for the Short-Shot Heart Rate Monitor.

Such considerations come from the recognition that the cardiac cycle performs the role of process synchronization, similar to the clock in a microelectronic circuit. As the heart synchronizes the body, all other phenomena can be related to this. A typical example is the ‘condition monitor’ that evaluates the change of the blood pressure in response to change in the heart rate.

In all, we discuss here a physically-inspired behavioral model. It does not aim to be medically correct in the physical details, but only to give medically correct results within the limitations of the current model. Therefore it reports when the analysis finds data that are not in agreement with the model assumptions. As such, it is fit for the consumer market while providing medically correct results but does not endeavor to replace the physician.

ACKNOWLEDGMENT

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KEY TERMS AND DEFINITIONS

Body-Area-Network: A wireless network of wearable computing devices.

eHealth: The use of electronic processes and communication for healthcare practice.

Event-Driven Architecture: A software pattern where loosely-coupled nodes are activated by self-contained events.

mHealth: An abbreviation for mobile health, the use of mobile devices for medicine and public health.

Perfusion: The body process delivering capillary blood in its biological tissue.

Photoplethysmography: The use of a pulse oximeter to illuminates the skin and measure changes in light absorption.

PPG: Signal is the photoplethysmographical time-series that is extracted by an oximeter on basis of light reflection on the skin.

Pulse Oximetry: A non-invasive method for measuring a patient's O₂ saturation.

Quantified Self: A movement to incorporate data acquisition technology for health in aspects of a person's daily life.

Reflective Light: Visual light that is sensed from the reflection on the skin.

Smart Phone: A mobile phone with more advanced capability than basic feature phones, such as a vision sensor.

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Smart Watch: A wristwatch that at least monitors cardiac effects.

Spectroscopy: Delivers the absorption frequency to indicate the presence and amount of matter.

Time-Triggered Architecture: A software pattern to execute one or more sets of tasks according to a pre-determined task schedule.

Wearable Technology: Comprises clothing and accessories incorporating computer and advanced electronic technologies. Meant for the consumer market, it has a clear aesthetic, say fashionable, aspect.

Chapter 8

Reliability of IoT– Aware BPMN Healthcare Processes

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ABSTRACT

BPMN (Business Process Model and Notation) has become the de-facto business process modelling language standard. Healthcare processes have been increasingly incorporating participants other than humans, including Internet of Things (IoT) physical devices such as biomedical sensors or patient electronic tags. Due to its critical requirements, IoT-aware healthcare processes justify the relevance of Quality of Services aspects, such as reliability, availability, and cost, among others. This chapter focuses on reliability and proposes to use the Stochastic Workflow Reduction (SWR) method to calculate the reliability of IoT-aware BPMN healthcare processes. In addition, the chapter proposes a BPMN language extension to provide processes with reliability information. This way, at design time, modellers can analyse alternatives and, at run time, reliability information can be used to select participants, execute services, or monitor process executions. The proposal is applied to an Ambient Assisted Living system use case, a rich example of an IoT-aware healthcare process.

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INTRODUCTION

Business Process Management has been applied to the healthcare domain, improving several practical aspects regarding the quality of care services provided to patients (Reichert, 2011; Russo & Mecella, 2013). These aspects include, from a healthcare professional perspective, reduced number of procedures, cost optimizations, increased information availability in critical situations and better decision making, among others. From a patient perspective, they include reduced length of stay, decrease of evasiveness to treatments and a global care process-awareness.

BPMN (Business Process Model and Notation) (OMG, 2011) is becoming the leader and de-facto standard in business process modelling (Harmon & Wolf, 2014). Considering the healthcare domain, BPMN has been used to model and execute various processes, both administrative and medical processes (Svagård & Farshchian, 2009; Rojo, Calahorra, & Ruiz, 2010; Strasser, Pfeifer, Helm, Schuler, & Altmann, 2011; Scheuerlein et al., 2012; Cossu et al., 2012; Müller, Prüfer, & Stöhr, 2014; Braun, Schlieter, Burwitz, & Esswein, 2015).

In addition, the healthcare domain presents itself as an ideal playground for Internet of Things-related scenarios (Pang, 2013). Known applications include real-time location systems, patient flow management, remote health monitoring, fitness programs, chronic diseases, and elderly care. For this, there are several IoT-related solutions commonly based on smart devices, including mobile devices, sensors, imaging devices and electronic text tags. Together with communication gateways or through direct communication protocols, they can bring timely and up-to-date information to Information Systems and the Organization. IoT-based healthcare services are expected to reduce costs, enrich the user's experience, increase the quality of life, and the number of patients served (Islam, Kwak, Kabir, Hossain, & Kwak, 2015).

However, healthcare processes are highly time sensitive and critical due to the impact that an error may have regarding, for instance, patient safety or information security and confidentiality. In Islam et al. (2015) the authors identify several challenges, signalling the Quality of Service (QoS) as an important requirement that must be assured in the application of IoT in healthcare. In this context, measuring reliability of a certain healthcare process that uses smart devices, such as sensors, can prevent a number of issues. These can range from a simple medical appointment delay or absence, to a serious hazard involving medical prescriptions of wrongly identified patients, or inappropriate emergency assistance with potential fatal consequences.

Calculating reliability of sensors has already been proposed (see, for instance, Parente et al., 2011; Siewiorek & Swarz, 2014). Nevertheless, these proposals focus on a particular device or type of devices, lacking on the evaluation of a global reli-

ability regarding the remaining process tasks and control-flow elements where they participate. Furthermore, decision making based solely on reliability information of certain sensor/sensor network is usually very limitative.

In this chapter, the authors propose an innovative approach to the calculation of reliability in IoT-aware healthcare processes. For this, the BPMN is used to first model the process. Then the Stochastic Workflow Reduction (SWR) algorithm from Cardoso (2002) is used to calculate reliability, based on the reliability information of each element of a BPMN process (including Tasks, and Events), and in the iterative reduction of these elements to a final process element representing the whole process's reliability. To be able to register reliability information for each BPMN process element, the authors propose the *relyBPMN* extension. A three-step method is detailed to accomplish it, using the native BPMN extension mechanisms. The authors apply then the approach to an IoT-aware healthcare process use case, in order to calculate its reliability, and simulate different scenarios to evaluate which conditions are necessary to ensure a given reliability level.

Using this approach of calculating reliability for a BPMN process model will allow better decision making. For instance, calculating reliability for a certain part of a process model (at design time) can help process designers to assess the need of modelling other alternative paths, or to foresee more instances of a certain type of sensors in a multi-instance subprocess, in order to assure better patient safety. At runtime (i.e., within a running process instance), a certain task resource can be selected taking into account the process instance's reliability so far, or even the predicted reliability impact of further tasks, resources, events or decision nodes, regarding their actual or historic reliability information.

This chapter is organized as follows: next section provides background concepts and discussions supported by a literature review regarding the main topics of BPM in healthcare, IoT and reliability. Next, the *relyBPMN* extension is presented, followed by the calculation of business process reliability for BPMN processes. The authors proceed with a description of IoT-aware healthcare processes based on Ambient Assisted Living (AAL) architectures, and present a use case scenario for a healthcare process based on Body Area Network (BAN) sensors. Finally, the chapter ends with future research directions and conclusions.

LITERATURE REVIEW

In the last years, we have witnessed the increasing use of Business Process Management (BPM) methodologies and tools in the healthcare domain, in order to reduce costs and improve quality of care (Russo & Mecella, 2013). They have been used both

for administrative/organizational processes and medical processes. Administrative/organizational processes support administrative tasks, such as patient admission, discharge, transfer, appointment planning, and scheduling of resources. Medical processes support diagnostic and therapeutic procedures.

As BPMN becomes the de-facto standard in business process modeling, we can find in the literature some works describing the use of BPMN to model and execute healthcare processes. For instance, Rojo et al. (2010) use BPMN to model and execute anatomic pathology sub-processes within the programmed surgical patient process in a Spanish hospital; Strasser et al. (2011) use BPMN to define and reconstruct clinical processes in order to monitor patients from admission to discharge – their main goal is to compare, analyse and evaluate these processes to improve healthcare processes and, consequently, to enhance cost control and care quality; Svagård & Farshchian (2009) model existing chronic care processes, which are collaborative by nature, since chronically ill patients often need to move from one institution to another; Scheuerlein et al. (2012) model the processes for the treatment of colon and rectum carcinoma; Cossu et al. (2012) define processes for diagnosis and treatment of chest pain; and Duske, Müller, Prüfer, & Stöhr (2014) model a treatment process for stroke patients. More recently, Ilahi, Ghannouchi, & Martinho (2014) use BPMN to model home healthcare processes and assess their needs in terms of flexibility, and Braun et al. (2015) extend BPMN with additional domain specific concepts for modelling clinical processes. Martinho, Rijo, & Nunes (2015) perform a comparison of process complexity of administrative (BPMN) healthcare processes of a hospital, before and after the adoption of a new scheduling system.

Besides the increasing use of BPMN in healthcare, technology advances make it also possible to use the Internet of Things (IoT) to improve healthcare processes. In particular, considering patient care, IoT can be used in, for instance, AAL services or patient monitoring to assist in pediatric and elderly care, chronic disease, and private health requirements (Rodrigues, Alves, Silveira, & Laranjeira, 2012; Rashidi & Mihailidis, 2013; Memon, Wagner, Pedersen, Beevi, & Hansen, 2014; and Islam et al., 2015).

By using web services, IoT information and functionalities can be easily integrated in BPMN processes (Zeng, Guo, & Cheng, 2011). In addition, some proposals even support the definition of the IoT behaviour with BPMN-based language, with the same abstraction level of the remaining process (Caracaş & Bernauer, 2011; Caracas, 2012; Casati et al., 2012; Tranquillini, 2012; Sungur, Spiess, Oertel, & Kopp, 2013). The IoT behaviour is defined in a separate BPMN pool and the interactions amongst pools are specified with BPMN collaboration diagrams. The main challenge of these proposals is translating this behaviour to a programming language and code to be understood and executed by the IoT-associated devices (such as sensors and actuators).

However, as stated for instance by Meyer, Sperner, Magerkurth, & Pasquier (2011a), using IoT in business processes (i.e. IoT-aware business processes) presents specific requirements, some of them related to Quality of Service (QoS). This way, there are some works in literature that extend BPMN with QoS information, such as reliability, availability, cost and performance, among others. Meyer et al. (2011a) propose a BPMN extension where they use annotations to model the certainty of information that sensor devices provide (from 0 to 100%) and the availability/potential fault of these devices. Chiu & Wang (2013) also propose a BPMN extension where a domain specific task named IoT Task can include information about availability and fault tolerance rates. The authors state that IoT tasks can refer to this information to decide whether they can finish or they have to handle an exception. Considering performance requirements, Caracas & Bernauer (2011) distinguish transmission modes, such as broadcast and unicast, as well as communication protocols, such as IEEE 802.15.4 and TCP/IP by using the category element of the BPMN message. Sungur et al. (2013) use performance annotations to prioritize between reliability and energy consumption of sensor devices.

To provide BPMN business processes with IoT quality information, Meyer, Sperner, & Magerkurth (2011b) extends the BPMN *Task* element with two additional elements: the *IQMCalculated* element, which stores the IoT Information Quality Metric (IQM), calculated from the USDL service description, and the *IQMManual* element, which stores the minimum required value. They calculated these metrics by using time, space, reliability and traceability quality of information parameters available in the USDL service description. This way, process modellers can:

1. Define the minimum required IQM values for real-world process tasks,
2. Choose from different resource service taking into account their IQM values, and
3. Deal with low quality resource services by changing the process.

Starting from this BPMN extension that Meyer et al. define and considering that quality of information cannot be assessed alone due to its interdependency with access cost, Martinho & Domingos (2014) propose to include two additional elements to the BPMN task element: the *CostMCalculated* element that stores the cost metric calculated from the USDL service description and; the *CostMManual* element that stores the maximum required value.

The main focus of the previous works is to overcome BPMN expressiveness limitations to include information about QoS. In the following, the authors present the literature review about computing reliability for composite tasks or even for the overall process.

Koren and Krishna (2007) define *reliability of a system at time t* , denoted by $R(t)$, as the probability of the system to be up continuously in time interval $[0, t]$. This metric is adequate for systems operating continuously, where a single momentary failure can have a high or even critical impact.

In the context of workflow modelling, Cardoso (2002) defines task reliability as the probability that the components operate on users demand, following a discrete-time model. The failure rate of a task is the ratio number of unsuccessful executions to scheduled executions. This way, the task reliability, denoted by $R(A)$, is

$$R(A) = 1 - failureRate(A),$$

the opposite of the failure rate.

Traditionally, reliability has been a major concern for networking, critical and real-time applications, as well as middleware (Parente et al., 2011; Siewiorek & Swarz, 2014). The increasing use of workflow systems, specifically, in more critical systems, justifies the works on workflow reliability. Cardoso (2002) proposes a predictive QoS model for workflows and web services that, based on atomic task QoS attributes, is able to estimate the QoS for workflows, considering the following dimensions: time, cost, reliability, and fidelity. This author developed the Stochastic Workflow Reduction (SWR) algorithm, which applies a set of reduction rules to the process, iteratively, until only one activity remains. The QoS metrics of the remaining activity corresponds to the QoS metrics of the process. Cardoso defines reduction rules for the following construction blocks: sequential, parallel, conditional, loop, fault tolerant, and network systems. He applies his proposal to the METEOR workflow management system (Krishnakumar & Sheth, 1995).

Coppolino, Romano, Mazzocca, and Salvi (2007) generalize the Cardoso proposal, covering all the generic workflow patterns of van der Aalst, Ter Hofstede, Kiepuszewski, & Barros (2003), to estimate the reliability of web services compositions.

Mukherjee, Jalote, & Nanda (2008) compute the reliability of WS-BPEL processes taking into account most of the workflow patterns that WS-BPEL can express, while Distefano, Ghezzi, Guinea, & Mirandola (2014) method also incorporates advanced composition features such as fault, compensation, termination and event handling. Rodrigues et al. (2012) use Unified Modeling Language (UML) models, which specify system component interactions, annotating them with component failure probabilities. They convert them into a formal executable specification, based on a probabilistic process algebra description language, which are executed on PRISM. This way, they can, for instance, identify the components that have the highest impact on the reliability of the system.

Respício and Domingos (2015) calculate the reliability of BPMN business processes by using the Stochastic Workflow Reduction method of Cardoso in (Cardoso, 2002; Cardoso, Sheth, Miller, Arnold, & Kochut, 2004). To meet this goal, they extend BPMN with reliability information and they identify the BPMN process blocks for which they can apply a reduction rule.

The work presented in this chapter applies and extends the proposal of Respício & Domingos (2015). It includes a process scenario from the healthcare domain, more specifically, an IoT-aware and AAL-enabled healthcare process, and details the study of Martinho, Domingos, and Respício (2016).

relyBPMN: THE BPMN EXTENSION FOR RELIABILITY

Despite BPMN 2.0 meta-model already defines an extensibility mechanism, it leaves out the methodological guides to develop BPMN extensions. Based on the work proposed by Stroppi, Chiotti, & Villarreal (2011), in this section, the authors define the *relyBPMN* extension, by following these three steps:

1. Definition of the Conceptual Domain Model of the Extension, using the Unified Modelling Language (UML);
2. Definition of the BPMN Extension Model, defining the extension in terms of the standard BPMN extension mechanism; and
3. Definition of the XML Schema Extension.

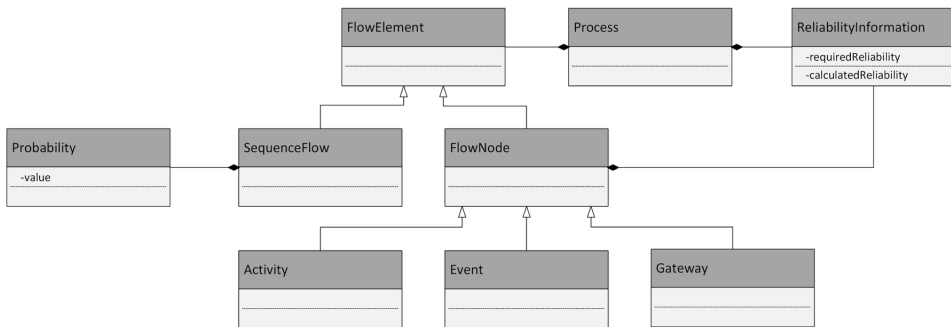
Respício and Domingos (2015) present the first approach to step 3 using a XML Schema. The following sections present the models for steps 1 and 2 as well as a more detailed XML Schema Extension.

Conceptual Domain Model for Process Reliability

The first step consists in defining the concepts of the domain and their relationships. Processes and flow nodes (Activities, Events, and Gateways) include reliability information, as illustrated in Figure 1. The `requiredReliability` defines the minimum accepted value for the process or flow node. For atomic activities and events, `calculatedReliability` corresponds to a known value determined, for instance, during a training period, while for decomposable activities (sub-processes) and processes, it corresponds to reliability calculated by using the Stochastic Workflow Reduction method of Cardoso (2002).

In addition, `SequenceFlow` elements include the probability value, which is used in conditional `SequenceFlow` elements within conditional process blocks or loop

Figure 1. UML conceptual model for process reliability



process blocks. The probability value of a conditional SequenceFlow defines the probability of the process execution path of taking it.

BPMN Model for relyBPMN Extension

The extensibility mechanism of the BPMN 2.0 meta-model standard (OMG, 2011) already considers the possibility of extending standard BPMN elements by adding non-standard attributes and other elements. According to this native extension mechanism, a BPMN extension consists of the following elements:

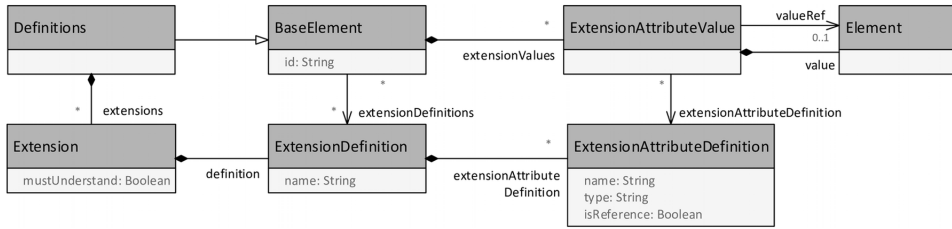
1. Extension;
2. ExtensionDefinition;
3. ExtensionAttributeDefinition; and
4. ExtensionAttributeValue.

The ExtensionDefinition element defines and groups additional attributes. It can be defined independently of the BPMN model with which it is to be associated. To use an ExtensionDefinition within a BPMN model definition, it must be associated with an Extension element that binds it to a specific BPMN model definition together with its ExtensionAttributeDefinition. This latter element defines the list of new attributes. Each of these attributes is defined by its name and type.

The Extension element is contained within the BPMN Definitions element and, therefore, is defined at the BPMN model definitions level. This way, through the ExtensionDefinition element the Extension element is available to be associated with any BPMN element that subclasses the BPMN BaseElement. Figure 2 presents the class diagram for a BPMN extension.

Figure 2. BPMN extension class diagram

Source: OMG, 2011.



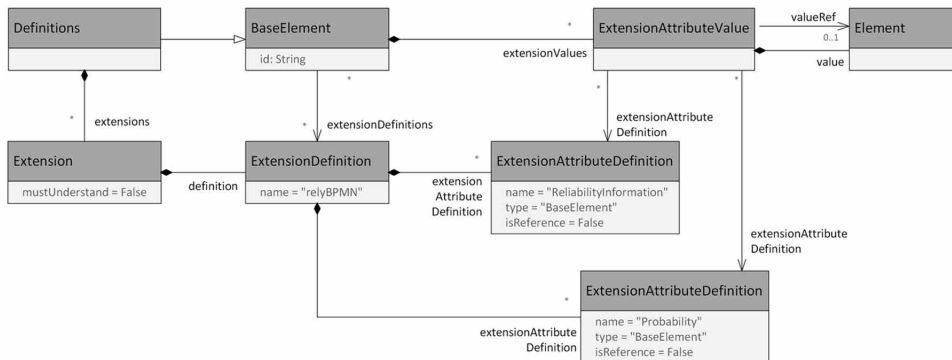
The class diagram of the *relyBPMN* extension model is defined in Figure 3. The value of the ExtensionDefinition attribute name corresponds to the extension name: *relyBPMN*. The mustUnderstand attribute of the Extension class has the false value, i.e., a compliant BPMN tool may ignore the extension. The *relyBPMN* extension has two new attribute, the ReliabilityInformation and the Probability, defined as ExtensionAttributeDefinitions. This way, every BPMN element that subclasses the BaseElement element can use these new attributes.

XML Schema for the relyBPMN Extension

The BPMN standard has two representations of its elements. The previous section describes the language concepts using the Meta Object Facility meta-model. This section presents the XML Schema.

These two representations are not equivalent, as explained in the following:

Figure 3. *relyBPMN* extension class diagram



1. The ExtensionDefinition class defines and groups additional attributes. Since XSD Complex Types already satisfy this requirement, this type is not applicable when the XML schema interchange is used (OMG, 2011), and
2. The ExtensionAttributeDefinition defines new attributes and the ExtensionAttributeValue contains the attribute value. Since the XSD mechanisms for supporting “AnyAttribute” and “Any” type already satisfy this requirement, these types are not applicable when the XML schema interchange is used.

This way, considering the four elements that the BPMN extensibility mechanism provides, the XML Schema only includes the Extension element, as illustrated in Figure 4. BPMN extensions are defined using XML components in a separate XML Schema documents, with their own namespaces, and imported through the TImport element.

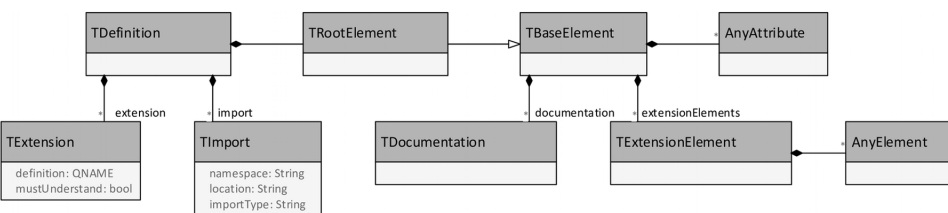
Listing 1 presents the *relyBPMN* extension XML Schema. The *relyBPMN* ExtensionDefinition element is represented with a <xsd:group> element, while the ExtensionAttributeDefinition elements are represented with the <xsd:element> element inside the <xsd:group> element. The <xsd:complexType> XML Schema element is used to define the structure of extension attributes types (it is not possible to define them using the BPMN meta-model).

The XML Schema presented in Respício & Domingos (2015) includes one <xsd:group> element *reliabilityInfo* handling only one attribute for the calculated reliability value (in that case named *ReliabilityValue*).

BUSINESS PROCESS RELIABILITY CALCULATION

The business process reliability value is calculated by using the Stochastic Workflow Reduction (SWR) method that Cardoso (2002) proposes. This method applies a set of reduction rules to the process, iteratively, until only one activity remains. The reliability of the remaining activity corresponds to the reliability of the process.

Figure 4. BPMN extensibility XML schema



Listing 1. relyBPMN XML schema

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns="http://www.fc.ul.pt/relybpmn " xmlns:bpmn="http://www.
omg.org/spec/BPMN/20100524/MODEL " targetNamespace="http://www.
fc.ul.pt/relybpmn ">
  <xsd:import namespace="http://www.omg.org/spec/
BPMN/20100524/MODEL " schemaLocation="BPMN20.xsd"/>
  <xsd:group name="relyBPMN">
    <xsd:sequence>
      <xsd:element name="ReliabilityInformation"
type="tReliabilityInformation"
minOccurs="0" maxOccurs="unbounded"/>
<xsd:element name="Probability" type="tProbability" minOc-
curs="0"
maxOccurs="unbounded"/>
    </xsd:sequence>
  </xsd:group>
  <xsd:complexType name="tReliabilityInformation"
abstract="false">
    <xsd:attribute name="requiredReliability"
type="xsd:decimal"/>
    <xsd:attribute name="calculatedReliability"
type="xsd:decimal"/>
  </xsd:complexType>
  <xsd:complexType name="tProbability" abstract="false">
    <xsd:attribute name="value" type="xsd:decimal"/>
  </xsd:complexType>
</xsd:schema>
```

Respício & Domingos (2015) apply the six reduction rules of Cardoso to BPMN, identifying the BPMN process blocks for which the reduction rules can be used. The next subsection overviews these process blocks, their corresponding reduction rules, and reliability values.

Reduction Rules for BPMN Process Blocks

Cardoso (2002) presents reduction rules for six process blocks:

1. Sequential,
2. Parallel,
3. Conditional,
4. Loop,
5. Fault-tolerant, and
6. Network.

BPMN provides more than one option to represent almost all these types of process blocks. The following systematization is mainly based on the works of White (2004) and Wohed, van der Aalst, Dumas, Ter Hofstede, and Russell (2006).

Sequential Process Block

In BPMN, a sequential process block is represented with a BPMN *Uncontrolled Flow*. A BPMN *Uncontrolled Flow* is a BPMN *Sequence Flow* that connects two activities without a conditional indicator (mini-diamond) or an intervening gateway. Figure 5 illustrates a BPMN sequential process block.

The reliability value of the reduced sequential block, designated as $R(AB)$, is the product of the reliabilities values of Activities A and B :

$$R(AB) = R(A) * R(B) \quad (1)$$

Parallel Process Block

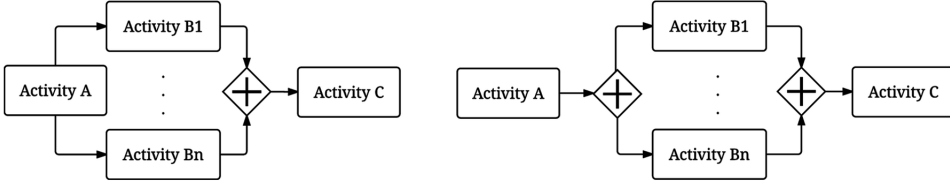
BPMN provides two options to represent concurrency, i.e., two or more activities that are executed in parallel. The preferred method for most situations uses multiple outgoing sequence flows. The other option uses a parallel gateway. Figure 6 illustrates both options.

The reduced parallel process block, designated as $B1n$, replaces the group of parallel activities (activities $B1, \dots, Bn$). Its reliability value, $R(B1n)$, is the product of the reliability values of each activity Bi :

Figure 5. BPMN pattern for sequential process block



Figure 6. BPMN patterns for parallel process blocks



$$R(B1n) = \prod_{1 \leq i \leq n} R(Bi) \quad (2)$$

Conditional Process Block

In BPMN, conditional process blocks are represented with exclusive gateways, branching points where alternatives are based on conditional expressions (cond1, cond2,..., default) contained within the outgoing sequence flows. Only one of the alternatives will be chosen. Exclusive gateways can be shown with or without the “X” marker. In case of a merge gateway, if all the incoming flows are alternatives, then the gateway is not needed, as shown in the left part of Figure 7.

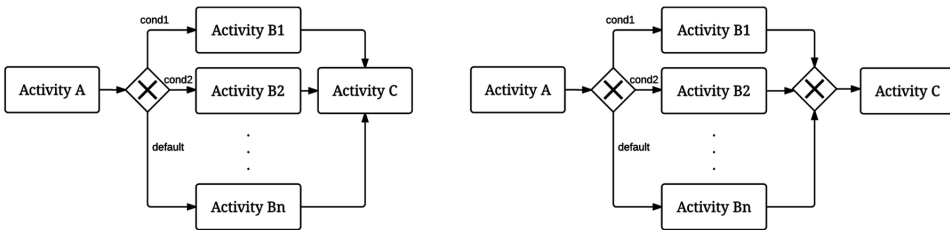
As the parallel process block, the reduced conditional process block, designated as $B1n$, replaces the group of alternative activities (activities $B1, \dots, Bn$).

To calculate the reliability value of the reduced conditional block we need to know the probability value of each conditional sequence flow p_i , i.e. the probability p_i that activity Bi is chosen to execute, where $\sum_{1 \leq i \leq n} p_i = 1$ and n is the number of alternative flows.

The reliability of the reduced conditional block, $R(B1n)$, is:

$$R(B1n) = \sum_{1 \leq i \leq n} p_i R(Bi) \quad (3)$$

Figure 7. BPMN patterns for conditional process blocks



Loop Process Block

BPMN has two mechanisms to represent loops:

1. **Standard Loop:** The activity is executed as long as its Boolean condition evaluates to true;
2. **Parallel Multiple Instances Loop:** Multiple instances of Activity are executed in parallel;
3. **Sequence Multiple Instances Loop:** Multiple instances of Activity are executed sequentially; and
4. **Sequence Flow Looping:** Loops are created by connecting a Sequence Flow to an “upstream” object.

Figure 8 illustrates each of these loop representations from left to right, respectively.

The reliability value of the reduced loop blocks that execute exactly k times, designed as $R(A')$ is:

$$R(A') = R(A)^k \quad (4)$$

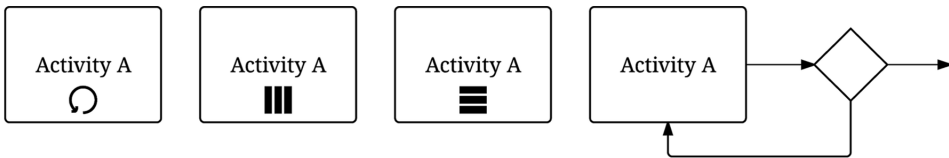
For the reduced block of the Sequence flow looping, its reliability value is:

$$R(A') = \frac{(1-p)R(A)}{1-pR(A)} \quad (5)$$

where p is the probability of executing the loop. An activity A that includes a loop may execute as follows: the loop is not performed, with reliability $(1-p)R(A)$, or the loop is performed once, with reliability

$$pR(A)(1-p)R(A),$$

Figure 8. BPMN patterns for Loop process blocks



or the loop performs k times, with reliability

$$\left(pR(A)\right)^k (1-p)R(A).$$

Thus,

$$R(A') = \sum_{k \geq 0} \left(pR(A)\right)^k * (1-p)R(A). \quad (6)$$

Summing the terms of the infinite geometric progression, we obtain

$$R(A') = \frac{1}{1-pR(A)} * (1-p)R(A) = \frac{(1-p)R(A)}{1-pR(A)}. \quad (7)$$

Fault Tolerant Process Block

While in Conditional process blocks only one of the alternatives will be chosen, in Fault Tolerant process blocks one to all of the alternative paths can be chosen.

In BPMN, Fault Tolerant process blocks can be represented with Inclusive Gateways or Complex Gateways. With Inclusive Gateways, alternatives are based on conditional expressions contained within the outgoing sequence flows, illustrated in the left side of Figure 9. Unlike conditional process blocks, each path is independent and, consequently, all combinations of paths may be taken. Alternatively, instead of using an inclusive gateway, it is possible to use conditional Sequence Flows, marked with mini-diamonds, as illustrated in the right side of Figure 9.

BPMN also represents Fault Tolerant process blocks with Complex Gateways. In this case, the modeller defines how many alternative paths are necessary to be executed (k out of n). Alternative paths can also be represented by conditional flows as illustrated in the right side of Figure 10.

Figure 9. BPMN patterns for fault tolerant process blocks: inclusive gateway

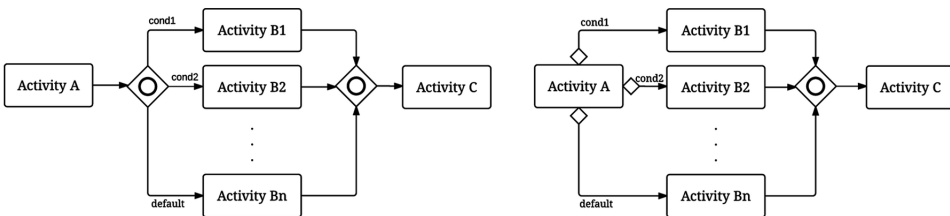
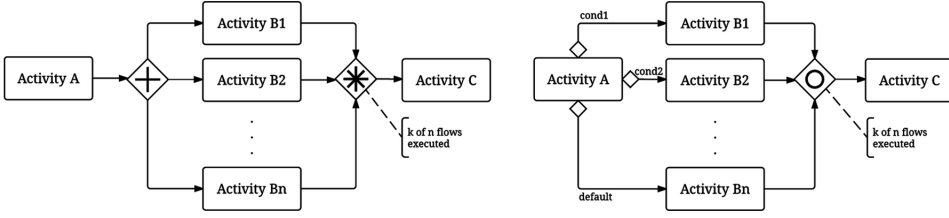


Figure 10. BPMN patterns for fault tolerant process blocks: complex gateway



The reduced fault tolerant process block, designated as $B1n$, replaces the group of alternative activities (activities $B1, \dots, Bn$). Its reliability value, $R(B1n)$, is:

$$R(B1n) = \sum_{I_1=0,1} \dots \sum_{I_n=0,1} \left(\phi \left(\sum_{i=1}^n I_i - k \right) \prod_{i=1}^n (1 - I_i + (2I_i - 1)R(Bi)) \right) \quad (8)$$

The reliability of a k -out-of- n system is given by the sum of the reliabilities of all the scenarios where at least k activities execute. Variable I_i is used to express whether activity Bi executes or fails, by setting $I_i = 1$ or $I_i = 0$, respectively. We consider the function $\phi(x) = 1, \text{ if } x \geq 0; 0$ otherwise, to determine which combinations of k activities out of n correspond to scenarios where at least k activities execute, and thus should be considered. For activity Bi the reliability value to consider is $1 - I_i + (2I_i - 1)R(Bi)$ which is $R(Bi)$, if Bi executes, and $1 - R(Bi)$, otherwise.

Network Process Block

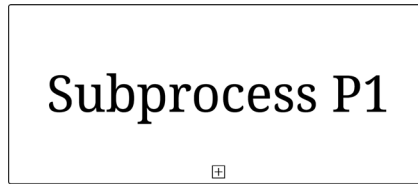
BPMN represents Network process blocks as sub-processes. A Sub-process is an Activity that encapsulates a Process, whose internal details have been modelled using BPMN elements. Figure 11 illustrates a BPMN sub-process.

Reliability value of the reduced block is set to the reliability value of the sub-process.

Reduction Rules for Additional BPMN Elements: Events and Collaboration Diagrams

The reduction rules presented in the previous section can be applied to process blocks that include events as they are applied to process block with activities.

Figure 11. BPMN pattern for network process blocks



Considering collaboration diagrams, reduction rules can be applied to the overall diagram by omitting pools and lanes. However, there are limitations on the block structured approach. For instance, it imposes one starting point and one ending point. To overcome this, it is necessary to transform the diagram by adding an Exclusive Event-Based Gateway (the new unique starting point) without any incoming sequence flows and with one outgoing sequence flow to each start event of the collaboration diagram. It is also necessary to convey an inclusive OR merge gateway with an incoming sequence flow, from each end event and without any outgoing sequence flows (Ouyang, Dumas, Ter Hofstede, & van der Aalst, 2007).

IoT-AWARE AMBIENT ASSISTED LIVING HEALTHCARE PROCESS

Ambient Assisted Living systems aim at improving the quality of life for people in all age phases by extending the time elderly people can live at home. They also help in promoting a better and healthier environment for patients at risk, improving the delivery of care where and when needed, and supporting carers, families and care organizations, for instance. They continuously monitor vital parameters of patients and can alert care people in case they detect emergency situations. They can also have a more active role by, for instance, auto injecting insulin, when the insulin level declines.

While it seems that the main motivation of AAL systems is to support assisting elderly people (see for instance H2020 calls of European Commission), they also present many advantages for patients suffering from chronic diseases such as diabetes, asthma and heart attacks.

Before presenting the IoT-aware healthcare AAL process model use case, this section includes an overview of AAL system architecture and of the reliability of its components.

Architecture of Ambient Assisted Living Systems

Ambient Assisted Living systems include four main components (see, for instance, Rodrigues et al., 2012; Rashidi & Mihailidis, 2013; Islam et al., 2015; and Memon et al., 2014):

1. **Body Area Network (BAN) Sensor Devices:** BAN sensor devices are used for monitoring different types of vital signs, such as body temperature (Istepanian, Hu, Philip, & Sungoor, 2011), blood pressure (Dohr, Modre-Opsrian, Drobits, Hayn, & Schreier, 2010), blood sugar (Istepanian et al., 2011), electrical activity of the brain (EEG), cardiac activity (Drew et al., 2004; Yang et al., 2014), and blood oxygen (Jara, Zamora-Izquierdo, & Skarmeta, 2013). While, for instance, cardiac activity, blood glucose and pressure can be measured through wearable sensors using techniques such as infrared sensing, optical sensing, and oscillometric; some other vital signs, such as Electroencephalography (EEG) can be invasive in case of specific applications. Indeed, BAN devices can be implanted inside the body, surface mounted on the body or external devices that humans can carry for instance, by hand, in bags or in clothes. When used with BAN actuators, BAN devices can auto inject insulin through a pump while monitoring the insulin level on a diabetic patient (Jara, Zamora, & Skarmeta, 2011);
2. **Body Area Network (BAN) Gateway:** The BAN gateway is responsible for the communication inside the BAN and to the home gateway. It can also execute a BAN application to validate sensor read values, aggregate data, analyse data, and identifying the situations to activate actuators. Body sensors and actuators communicate with each other and with the BAN gateway. Most of them use wireless technologies, such as IEEE802.15.4 /ZigBee (IEEE, 2011). The latest international standard for wireless BAN (WBAN) is the IEEE802.15.6 (IEEE, 2012);
3. **Home Gateway:** Home gateways, such as smart phones or wireless routers, provide the connectivity to the internet, and, this way, to the health monitoring system. Home gateways communicate with a BAN gateway and BAN devices through wireless technologies (Bluetooth or WiFi, for instance);
4. **Health Monitoring System (HMS):** With health monitoring systems, care-givers and physicians can monitor patients remotely.

Figure 12 illustrates a typical architecture of an AAL system, taking into account this previous numbering regarding the four main components. It includes four BAN sensors (1), which measure/observe physical signs and communicate directly with a BAN gateway (2). In turn, this gateway can communicate with one or more

home gateways (3), which are represented as a smartphone and a wireless router in Figure 12. From here, sensor measured data and/or other kind of messaging can be sent to/received from a Health Monitoring System (4), which is being operated by a skilled health professional.

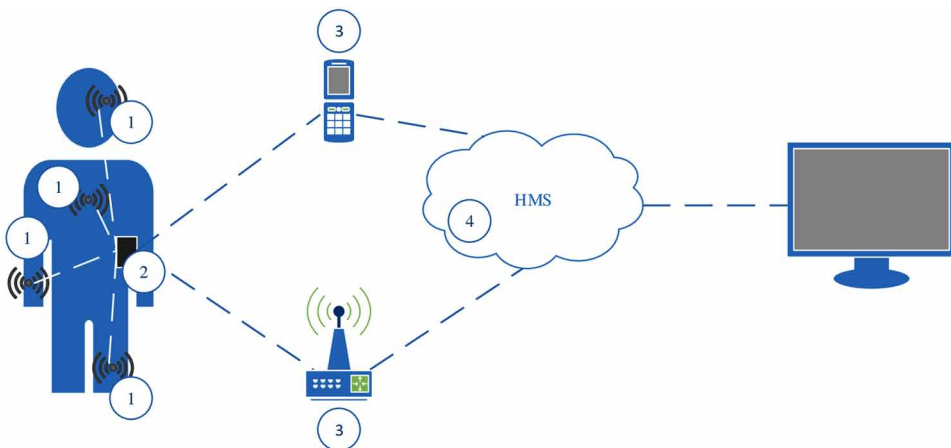
Reliability of AAL System Components

The reliability of AAL systems is a critical requirement as it can lead to misdiagnosis, treatment errors, and fatal consequences. This section discusses how and why the reliability value of each component of an AAL system can take different values.

Firstly, BAN devices (sensors and actuators) reliability depends on their quality and manufacturer. The mean-time between failures (MTBF) metrics can be used to assess it (McNaull, Augusto, Mulvenna, & McCullagh, 2012). Moreover, sensors data quality (accuracy) also interferes with reliability as anomalous values can be discarded, for instance, in the BAN gateway. Quality of data depends on sensor calibration as well as on the correct sensor use and application. For instance, other heat sources can affect temperature sensors.

Parente et al. (2011) present a use case where they monitor the health of patients considering heart activity and body activity. To monitor the heart activity, the system uses three devices: a heart rate monitor, a pulse oxymeter, and a sphygmomanometer. The system monitors the body activity of patients by using an accelerometer on their knees and a motion detector in the room. Taking into account the reliability of each device and the required reliability of the system, the authors determine the minimal combinations of sensors the system need.

Figure 12. Typical AAL system architecture with the four main types of components



BAN gateways may evaluate sensor data and detect anomalous and inconsistent values, considering the expected ones, which may have been established during the testing period of the AAL system (McNaull et al., 2012). In case of anomaly, erroneous sensor values are discarded and BAN gateways can read new sensor values. If the problem persists, the BAN gateway can alert the health monitoring system. These additional functionalities can increase the reliability of the system. Another way to increase system reliability is by defining a fault tolerant behaviour for the BAN gateway.

Considering the architecture of the overall system, the use of BAN gateways contributes to the decentralization of AAL systems, and consequently, decreases the number of messages exchanged with the monitoring system and its processing activities.

Reliability of wireless networks, such as ZigBee, WiFi, and Bluetooth, depends on interferences of other devices, obstruction of the signal due to lifts or wall, and attenuation, i.e., the strength of the signal reduces during transmission. In their study Baig, GholamHosseini, Connolly, & Kashfi (2014) compare wireless transmitted data with manual recorded data and hospital collected data. They use a total of approximately 2500 transmissions of 30 hospitalized patients and they conclude that, in wireless transmitted data, losses vary from 20% (blood glucose) to 80% (blood pressure and heart rate). They also conclude that data losses were mainly due to distance and data transmission delays were due to poor signals, signal drops, connection loss and/or poor location.

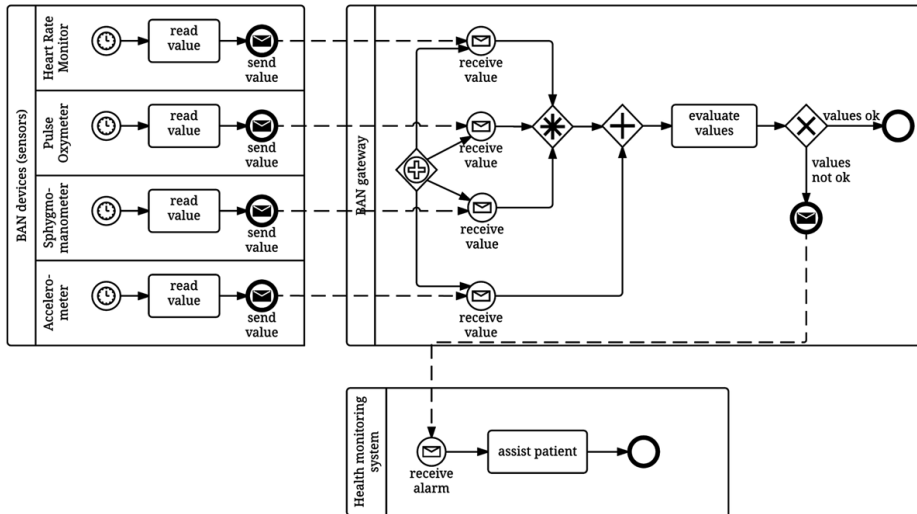
The IoT-Aware Healthcare AAL Process Model

This section describes the simplified IoT-aware healthcare AAL BPMN process model considered as use case in this chapter (Martinho et al., 2016). It is based on the processes presented by Bui & Zorzi (2011) and Dar, Taherkordi, Baraki, Elias-sen, & Geihs (2014). It also considers the process proposed by Meyer et al. (2011a), which uses sensors but for a different application domain.

The BPMN process model is defined as a collaboration diagram and includes three pools, one for each component: BAN devices (sensors), the BAN gateway, and the health monitoring system (see Figure 13).

Sensors read values from the patient and send them to the BAN gateway. The process model illustrates that sensors perform these tasks from time to time by using a timer. Another way to model the interaction between sensors and the BAN gateway is by using the request-reply paradigm, where the BAN gateway starts the interaction asking for the values. In addition, depending on sensor computational capabilities, they can also filter the data they send by restringing it to the values that are considered relevant. However, for the reliability study that this chapter pro-

Figure 13. IoT-aware AAL BPMN process model



poses, these differences are not significant. Based on one of the scenarios that Parente et al. (2011) presents, sensors monitor the health of the patient considering heart and body activity. The set of sensors includes a heart rate monitor (HRM), a pulse oxymeter to measure the blood oxygen saturation, and a sphygmomanometer to measure the blood pressure and an accelerometer to monitor the body activity.

The BAN gateway receives data from each sensor. This behaviour is modelled with an Event-Based Parallel Gateway. The information about heart rate should be provided by at least two out of three devices (behaviour modelled with a Complex Gateway). After evaluating sensor values, the BAN gateway sends an alarm to the health monitoring system (HMS) to assist the patient, in case any emergent situation is detected.

Reliability Study

Initially, designers define values for required reliabilities (requiredReliability attributes), the minimum accepted reliability values. These values are added to the BPMN process model by using the *relyBPMN* extension. By also using the attributes the *relyBPMN* extension provides, they enrich the BPMN process model with values for the calculatedReliability and the probability value attributes. The calculatedReliability attribute is initialized with pre-estimated values for atomic activities and events. If the process includes any conditional sequence flows, the probability value attributes are also initialized with pre-estimated values. Next, by using the SWR

algorithm, the calculatedReliability attribute is calculated for sub-processes and, finally for the overall process (the collaboration diagram).

In the following, the application of the proposed method to assess the reliability of the collaboration diagram illustrated in Figure 13 is described.

The calculatedReliability attribute is initialised as follows:

1. For the “read value” activities of sensors, the values proposed by Parente et al. (2011) are used, considering, respectively, 0.8 for the HRM, 0.7 for the Pulse Oxymeter, 0.6 for the Shygmomanometer, and 0.9 for the Accelerometer;
2. For all “receive value” activities (the transmission from sensors to the BAN gateway), the value 0.992 is chosen according to the measures of Baig et al. (2014);
3. For the “receive alarm” activity (the transmission from the BAN gateway to the Health monitoring system), the value 0.99 is used, as this connection uses the WiFi network; and
4. For the remaining activities and events, such as the process start, the evaluation of the received values in the BAN gateway, and the “assist patient” activity, the value 1 is set.

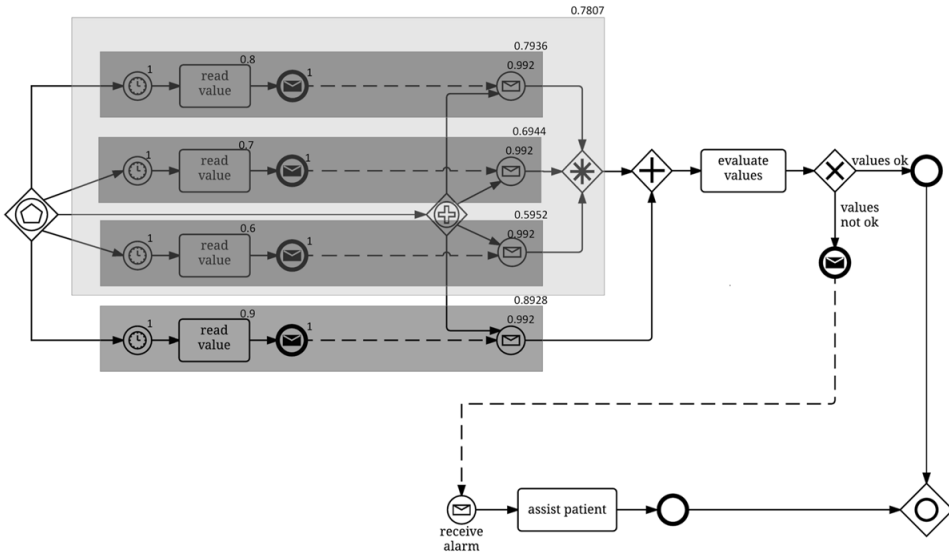
In addition, the requiredReliability value for all process activities and events is set to 0.6.

Figure 14 presents the process diagram used to apply reduction rules. As explained in section “Reduction rules for additional BPMN elements: events and collaboration diagrams”, polls and lanes are omitted and two gateways (the initial and the final) are added. The upper dark grey rectangle represents the reduction of the sequence <“event timer”, “read value”, “send value”, “receive value”>. The reliability value of the corresponding reduced block is computed by applying iteratively three times the reduction rule for sequential process blocks, thus obtaining the value 0.7936 ($0.7936 = (((1 * 0.8) * 1) * 0.992)$).

The reduction rule for the fault tolerant process block has four feasible combinations of receiving two out of three signal devices:

1. HRM, Pulse Oxymeter, Shygmomanometer with reliability $0.3280 = 0.7936 * 0.6944 * 0.5952$;
2. HRM, Pulse Oxymeter with reliability $0.2231 = 0.7936 * 0.6944 * (1 - 0.5952)$;
3. HRM, Shygmomanometer with reliability $0.1444 = 0.7936 * (1 - 0.6944) * 0.5952$; and
4. Pulse Oxymeter, Shygmomanometer with reliability $0.0853 = (1 - 0.7936) * 0.6944 * 0.5952$.

Figure 14. Applying reduction rules to the AAL BPMN process model



After applying this reduction rule, the reliability value of the reduced block is 0.7807, as illustrated in the light grey rectangle of Figure 14.

Then, the parallel process block reduction is applied and the reduced block has the reliability value of $0.6971 = 0.7807 \times 0.8928$.

Finally, by applying reduction rules for the remaining sequential process blocks, the reliability of the process is achieved and has the value 0.6901 ($0.6901 = 0.6971 \times 0.99$), a value above the required reliability, thus corresponding to a feasible reliability.

The second part of this study consists of assessing the impact on the reliability of the global process created by varying separately the reliability of elements. The study explores the following elements: the accelerometer sensor, the HRM sensor, the transmission from sensors to the BAN gateway and the transmission from the BAN gateway to the HMS. For each element under analysis, the reliability of that element is varied in the interval $[0.6; 1]$, using steps of 0.01. The reliability values for the remaining elements are fixed considering three scenarios:

1. The base case scenario fixes all the other reliability values to the ones of the original setting described above;
2. The worst case scenario fixes the reliability values of all sensors to their minimum value (0.6), to evaluate a pessimistic setting; and
3. The best case scenario fixes the reliability values of all sensors to their maximum value (0.99), to assess an optimistic scenario.

Figures 15-18 display the results of this study. Chart (a) illustrates the impact on the process reliability resulting from varying the accelerometer reliability for the three scenarios considered. Chart (b) shows the effects of varying the HRM reliability. This chart would be similar for reliability variations of the Pulse Oxymeter and Shygmomanometer sensors. This is due to the fact that all these sensors are part of the same fault tolerant pattern, and, consequently, variations on their reliability values have the same impact. The impact of varying the reliability of transmission from the sensors to the BAN gateway is displayed in chart (c), while chart (d) discloses the effect of considering different reliability values for the transmission from the BAN gateway to the HMS.

Firstly, the reliability of the transmission from sensors to the BAN gateway (chart (c)) is the element with the greatest impact on the reliability of the overall process. Secondly, the reliability of the process depends on the accelerometer reliability (chart (a)) and the transmission from the BAN gateway to the HSM (chart (d)), and, finally, on the reliability of a single sensor (HRM) (chart (b)).

For the best case scenario, variations of the value under analysis have a high impact on the process reliability for charts (a), (c) and (d), while the impact is minimum in chart (b), which corresponds to variations of the HRM, as well as Pulse Oxymeter and Shygmomanometer sensors. Considering the three scenarios, the worst case is the one that presents a smaller impact due to variations (charts (a), (c) and (d)), except for the HRM (chart (b)).

Figure 15. Impact on the process overall reliability by varying separate reliabilities: variation of accelerometer reliability (chart a)

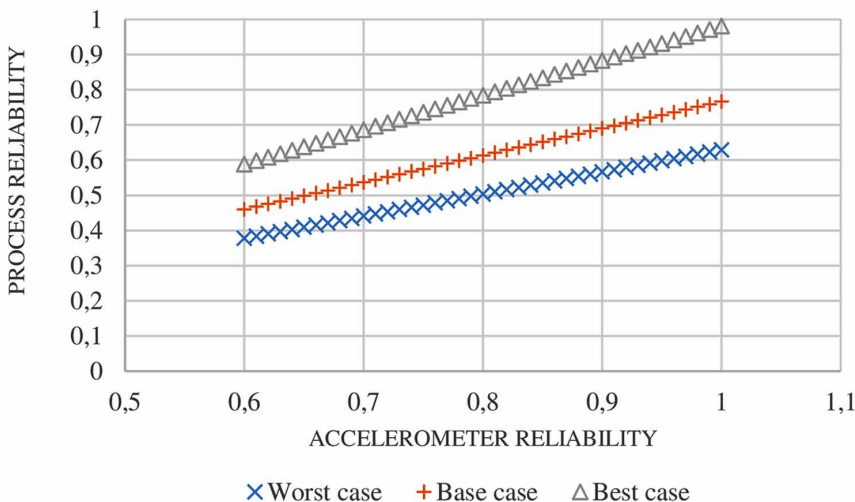


Figure 16. Impact on the process overall reliability by varying separate reliabilities: variation of HRM reliability (chart b)

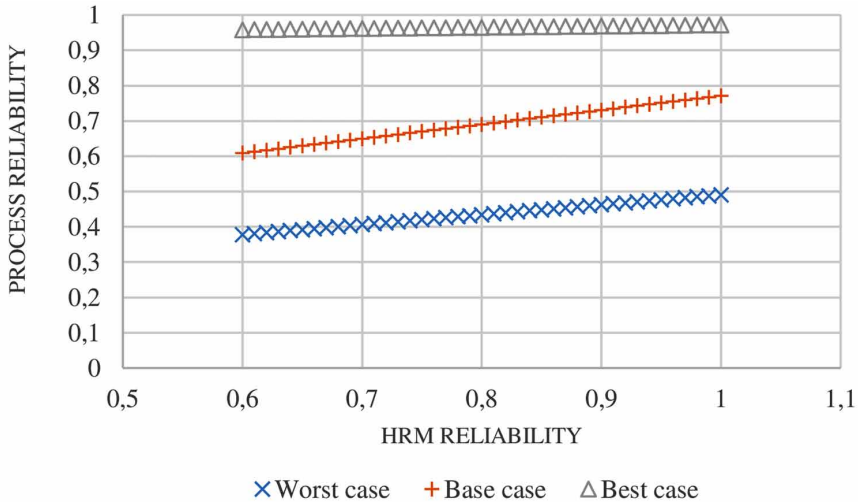
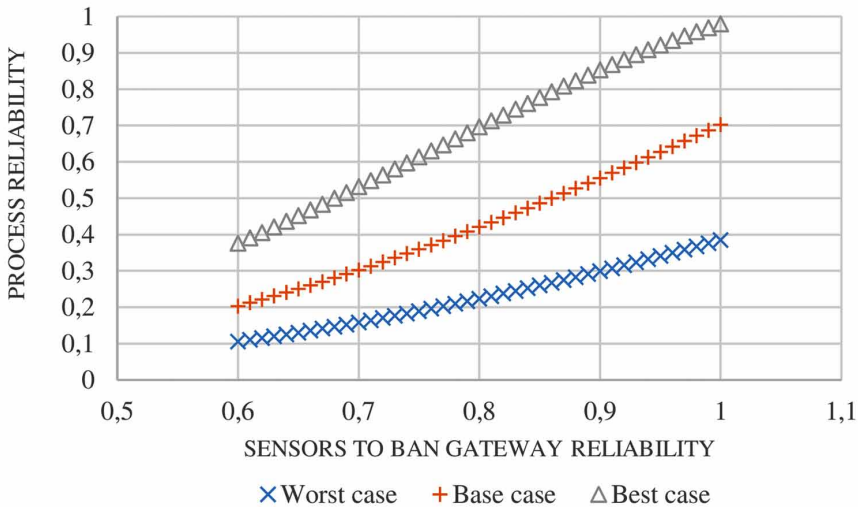


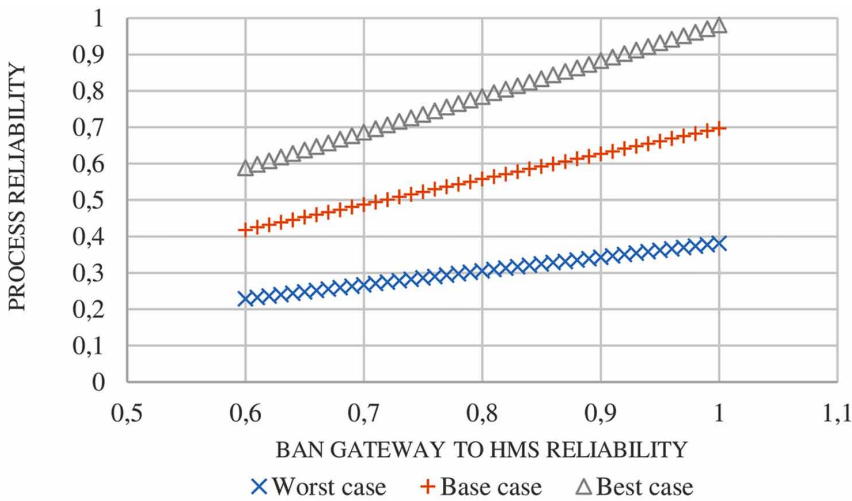
Figure 17. Impact on the process overall reliability by varying separate realities: variation of sensors to BAN gateway transmission reliability (chart c)



This study also allows determining in which conditions the minimum required reliability is attained. For instance, from chart (a) it is possible to infer that 0.8 (approximately) is the minimum value of the accelerometer reliability that allows reaching a feasible reliability of the process (0.6), in the base case, while for the

Reliability of IoT-Aware BPMN Healthcare Processes

Figure 18. Impact on the process overall reliability by varying separate realities: variation of BAN gateway to HMS transmission reliability (chart d)



same scenario, for the HRM sensor instead this value would drop to 0.6. For the worst case scenarios, the only situation where the feasible reliability can be met is with an accelerometer reliability value of at least 0.96. In addition, no conditions allow reaching an overall reliability greater than 0.8 in the base case scenarios. For the best case scenarios it is possible to attain a value of 0.9 in few situations: whenever the reliability of the accelerometer is greater than 0.92, for any reliability value of the HRM, when the reliability of the transmission from sensors to gateway is greater than 0.94, or for values of reliability greater than 0.92 for the transmission from the BAN Gateway to the HMS.

This study exemplifies how to proceed to assess different conditions of a BPMN healthcare process that involves IoT elements. This assessment can be made at design time to analyse the feasibility of the process, for instance, if a minimum level of reliability is assured. It allows to identify the elements which have the highest impact on process reliability and, therefore, to design the system architecture and set the requirements for system elements. Additionally, reliability can be computed at run time to monitor process executions hence providing an approach to identify low reliability services. In that case, the sensors timers can be adjusted as well as the transmission rate can be increased at run time.

FUTURE RESEARCH DIRECTIONS

Besides stated advantages of using BPM and the innovative approach to calculating partial or global reliability from a process model, other future research directions include additional and important aspects associated with IoT-aware healthcare processes that are reliability-dependent and can take advantage of a globally calculated reliability. These include, among others:

- Risk analyses from the security point of view, including vulnerabilities and attacks. Healthcare information is often subjected to strict security regulations, which impose extra security measures such as data anonymization, privacy, confidentiality and access control, in order to prevent information leaks. Dealing with IoT-aware healthcare processes brings additional security challenges such as computational, memory and energy limitations, or even tamper-related attacks. These challenges often cannot be ensured by traditional security techniques (Islam et al., 2015). Reliability can help on the choice of these techniques to prevent security risks;
- Reliability *versus* cost decisions, including the management of trade-offs between, for instance, sensors' battery life and more or less quality/timely information (Martinho & Domingos, 2014). Reliability information on a process can automatically help on the fine-tuning of these trade-offs, assuring the most suitable solution for a process instance where sensor's battery life and the quality of the information they provide are key factors;
- (Human or material) resource allocation optimization for a certain healthcare process, taking into account the process reliability actual and history data. This line of research can be pursued through diverse paths such as to maximize the reliability of processes that satisfy participant or material resource constraints, such as health professionals or certain medical exams scheduling. Another application includes minimizing differences of reliability observed in several process instances, to reach certain conditions of system equilibrium.

In addition, the authors are capitalizing previous experience with the jBPM Business Process Management System (BPMS) to incorporate the implementation of the *relyBPMN* extension proposed and detailed in this chapter.

CONCLUSION

As the use of BPM techniques and technologies is increasing in the healthcare domain, it is very important to take into account reliability information, not only for a particular activity in a process, but also for a group of activities, events and gateways, or even sub-processes and whole processes. This is even more critical when healthcare processes rely on IoT sensors or other devices to deliver a certain healthcare service to patients.

This chapter presents a comprehensive solution to calculate reliability in BPMN and IoT-aware healthcare processes. The approach includes an extension to the BPMN language to add reliability information for any particular process element (activities, events and gateways) or group of elements (sub-processes, loops and multiple-instance activities). Based on this information and on the calculus of the reliability of single and combined BPMN process elements, the authors apply the SWR algorithm to iteratively calculate reliability of process fragments or entire processes, through the reduction of all process elements to a single activity.

The use case scenario presented concerns an IoT-aware healthcare process, more specifically an AAL common application of BAN and health monitoring system, which architecture is also detailed. The healthcare process includes three process distinct participants and several sensors that must communicate with a BAN gateway to report biomedical measures for a certain home healthcare patient.

Base, worst and best case scenarios were considered for both individual and combined reliability values regarding the four BAN sensors and gateway included in the IoT-aware AAL BPMN process. The process reliability value was also calculated for these scenarios, taking into account reported reliability in the literature for these kinds of sensors. The impact of the variation of the individual reliability of the IoT process elements regarding the overall process could also be observed.

These reliability values can be used both at process design time and run time. This means that a process designer can take decisions, at design time, on the modelling of a certain IoT-aware healthcare process, based on reliability information of a particular sensor type to be used, or a calculated reliability for a certain path/branch of the process. At run time, resource allocation can be performed based on the reliability of a certain (human or material) resource, taking into account their actual availability. For instance, a number of health professionals can be scheduled to assist on an emergency care episode, based on their previous experience and outcomes. Similarly, an increased number of sensors can be initialized or actuated for a certain body biomedical measure, based on the need of a higher reliability on the correct reading and communication of certain values to a BAN gateway.

Besides the aforementioned direct advantages of having reliability information on an IoT-aware healthcare process, other applications of this information can be derived. These include using reliability to assess risks in critical safety healthcare scenarios, prevent security flaws or even manage and optimize resource usage.

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KEY TERMS AND DEFINITIONS

Ambient Assisted Living (AAL): A broader definition that includes methods, concepts, electronic systems, products and services which support the everyday lives of elder, disabled or chronically ill patients. The AAL techniques and technologies are user-centred, i.e., integrated directly into patients living environments and fitted to the needs of any particular patient.

Business Process: A set of activities, control-flow elements (e.g. sequences, decision, fork and join nodes), resources (e.g. human roles, materials) and data objects (documents, values) that are orchestrated together to deliver a certain product or service.

Business Process Management (BPM): Considers that organizations are composed by a set of business processes and focuses on the management of those processes. BPM can usually be described by a cycle of activities including the modelling, deployment, execution, monitoring, analysis and optimization of business processes. It also can refer to the techniques and technologies used in each of these activities.

Business Process Management System (BPMS): A kind of Information System that can execute business processes described or designed in a certain modelling language. BPMSs usually also comprise the management of running instances of business processes, and more advanced BPMS suites also include modelling studios and allow for a full configuration of an organisation, its roles and users interacting with business processes.

Business Process Modelling and Notation (BPMN): A modelling language based on a set of graphical notations that allow a visual design of a business process. Since 2004, the Object Management Group has been releasing major and minor versions of this language, which has become a standard de-facto for the modelling and also the execution of business processes.

Internet of Things: A network of physical objects or smart items (or simply, “things”) that are able, through the use of sensors and transmitters, to capture and send information of a certain environment to other objects or a centralised Information System. It also foresees that these objects can be sensed, monitored and controlled using an existing network infrastructure such as the Internet.

Reliability: Regarding Information Systems and systems engineering, reliability can be briefly described as the ability of a system or component to function under certain conditions over a period of time. Allied to business processes, it can be spanned to indicate the probability of a certain process element or group of process elements (such as activities, events, gateways or even resource allocations) to be executed with success.

Chapter 9

Thing Theory: Connecting Humans to Smart Healthcare

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ABSTRACT

As healthcare professionals and others embrace the Internet of Things (IoT) and smart environment paradigms, developers will bear the brunt of constructing the IT relationships within these, making sense of the big data produced as a result, and managing the relationships between people and technologies. This chapter explores how PolySocial Reality (PoSR), a framework for representing how people, devices and communication technologies interact, can be applied to developing use cases combining IoT and smart environment paradigms, giving special consideration to the nature of location-aware messaging from sensors and the resultant data collection in a healthcare environment. Based on this discussion, the authors suggest ways to enable more robust intra-sensor messaging through leveraging social awareness by software agents applied in carefully considered healthcare contexts.

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INTRODUCTION

Healthcare providers will enter location-aware smart environments with the expectation that their devices will integrate, their location will be incorporated, and the environment that they are within will specifically respond to their needs, as well as to the needs of their patients. Cooperation and coordination in complex environments requires people to have access to appropriate contextually sensitive information, some of which must be shared between them. To plan and design effective location-aware smart environments for healthcare, tools are required for integrating and responding to human needs and anticipating human intents and desires.

Humans depend upon successful cooperation with each other for their survival. As humans have evolved their environments, their communications structure and the messages that it produces have become more complex. Sharing or overlap of messages becomes critical in these highly heterogeneous environments, now comprised of people with many points-of-view using a range of channels for communication in multiple languages.

A location-aware healthcare smart environment is another layer within this already highly heterogeneous system of communication. Each component in a location-aware smart environment network can generate data and send messages that must be processed, understood and responded to in some manner. In a healthcare environment, well placed software agents can help manage critical messages shared between sensors, low level software agents and the people who act on this information, improving care for patients and outcomes for providers.

The authors' propose a framework based on the agency of both humans and environmental components: Thing Theory, a logic-based agent framework that evolves discussion on how to connect humans to a healthcare environment designed to function for their benefit.

BACKGROUND: THE HEALTHCARE ENVIRONMENT

Discrete pieces of the healthcare environment can be automated with Internet of Things (IoT) technologies, lessening the risk of mistakes from the outcome of multiple, multiplexed messaging and increasing the cooperation and abilities of technology to partner with people. In ideation, smart environments in healthcare are a great idea. In practice, much must be overcome for their successful deployment (Perry et. al 2013). Healthcare is a legacy system, largely regulated by government. In healthcare, many mistakes can have serious long term consequences, or can be fatal. Thus, any automated element within the healthcare domain must be well thought-out, robust and offer redundancy to enable successful application (Fairbanks et. al. 2014).

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With the IoT and healthcare there are many possible hypothetical scenarios that could be developed, from the critical, such as smart operating rooms, pharmacy services, and smart rooms for patient or psychiatric care units (Wears & Leveson 2008), to more mundane aspects of healthcare such as sections of preventative clinics or cafeteria and parking services. In healthcare, using the IoT for patient care and using the IoT to reduce costs can co-exist as mutual goals to improve healthcare quality, as joint benefits emerge from streamlining for efficiency and improvement of service quality (Chaudhry et. al. 2006). IoT strategies for healthcare should enhance and leverage legacy systems rather than reduce services as a by-product of automation.

The easiest early applications of the IoT could augment current automated elements of medical processes. An IoT within healthcare should be based on two broad concepts, distribution of functions to addressable devices where each device is responsible for a limited set of operations or capabilities, and a framework for flexibly integrating these devices so that developers, or even end users, can assemble the set of capabilities needed for some situational macro-task. Thus, IoT devices are tools that can be used for a vast range of purposes, rather than integrated systems per se. Integration emerges from instantiation of a given tool assemblage into a process through knowledge-based systems external to each device (Bradshaw et. al. 2013). This orientation largely mirrors the current situation, where space and individual tools are available for highly trained teams of individuals to integrate as needed to serve different medical procedures.

Minimally, connecting a device to the IoT framework requires transforming the external information a device produces and consumes into a form that can be transmitted over a network (Gubbi et. al. 2013). Examples of relatively straightforward healthcare IoT applications enable scales, blood pressure monitors, temperature and other visit quantification devices to share data directly by transmitting on demand usable measurements to a requesting (or watching) network agent. One or more network agents could manage the patient's record from each device. For example, as a patient enters a room, the room could be either activated by sensor, or could activate when a healthcare worker logs into the room's network and verifies the patient identity in the room. As the healthcare worker takes the measurements on various devices, the smart machines can send their readings to an open file, with buttons on the devices as options to skip logging the reading, or a way to do that in software in case there is a patient request to not update certain readings. Automating this data entry would save the time of the healthcare worker, who currently must scribe and re-enter the data into the computer after completing the data collection with the patient.

Most current devices used in medical contexts are designed with the intent to be administered by highly trained people. Current devices need to be actuated to take a useful measurement and to have the appropriate context for that measurement to

be useful. Some of these tasks are easier to address than others. An example of this might be to use IoT sensors to maintain room supply inventories. A simple sensor could determine if a supply level was low for cotton or alcohol pads, or other supplies, and this could trigger inventory resupply. In small clinics, this may not be useful, but in larger hospital settings, it may be helpful to have supply levels monitored and automated for refills. IoT sensors can monitor if someone is out of their bed, if the door has been opened, if the floor has extra weight on it, if the lavatory has been used or not, etc.

What can be measured, recorded and sent back as data in the healthcare environment is only limited by human imagination. What will be key to IoT healthcare scenarios are trusted methods to manage this low-level sensor data as messages between agents (Babar et. al. 2010). In addition, the data from these messages would serve the patient and clinics best if it could be managed and integrated in more meaningful ways that contribute to the well being of the patient and the efficiency of the healthcare enterprise. In healthcare especially, context of data collection is critical (Ahsan et. al. 2009).

If there is a patient who is mobile, and staying overnight in a room for observations or tests, whether or not they get up to use the lavatory (assuming it is not related to their tests) is less important in a smart environment, than if a patient records using the lavatory every 15 minutes and does not have a condition precluding that behavior. Simultaneously, patient data must be protected against uses that do not serve patient treatment, and in cases where it does, care must be taken so that the patient does not feel that they are a part of a larger surveillance state, only benefitting the healthcare clinic or provider, rather than patient well-being.

To achieve this in an IoT multi-agent healthcare environment, a trusted broker between individual agents and components and the healthcare workers and patients, is required to achieve secure and appropriate results. Thus, to move healthcare into the IoT realm, a universal ‘thing’ that can function as a source of trust and competence to organize other agents (Atzori et. al. 2011) while securing and protecting patient data, is required.

THING

An Agent Based Multiplexed Message Manager

The 1960’s Addams Family television series was based on a cartoon by Charles Addams (The Paley Center for Media, n.d.). The Addams Family lived in an enormous old mansion, full of taxidermy and other curiosities, located adjacent to a cemetery near caves, quicksand, and a swamp. The character of Thing is a disembodied hand

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(and forearm) that has been with the family for many years and is described as both a ‘family retainer’ and ‘friend.’ It inhabits a series of tabletop boxes in different rooms of the house that could be compared to a type of roughly cobbled physical network.

Thing also inhabits plant pots, clocks, the breadbox, glove compartments, tree roots, and other devices to use as a base for interaction. Thing communicates with the family by gestures, sign language, writing out notes, or tapping out messages in Morse code. Thing serves the family by accessing a portal in contextual proximity to what is needed. Thing will answer the phone, by taking the receiver off the hook (and later replacing it), pour the tea, retrieve and deliver the mail, play castanet accompaniment to the Butler’s harpsichord recitals, light cigars, return hats, offer advice, put its finger on a bow for tying up a present, or whatever else might be needed or desired at the precise moment required, in the precise room or context needed. Thing is not only a ubiquitous agent, but an anticipatory one that migrates within the environment. Although the family displays a “Beware of the Thing” sign on their front gate, Thing is shown to be courteous, friendly and helpful.

The authors consider the Addams Family’s Thing, minus the Uncanny Valley issues (Masahiro, 1970), as a good potential starting point for how agent behavior and interaction could support people in location-aware smart environments, including those within healthcare. The sensing, response and location-awareness of Thing is a useful aspirational model, even if the goal is not for disembodied hands to pop out of boxes to assist a patient. As an agent of sorts, Thing learned about and possessed data knowledge of every member of the household, their preferences, needs and desires, and was sensing and aware as to what type of contribution it could make to the successful outcome of their actions. Thing worked with their location and required nothing from them to be able to assist them, outside of their accepting its non-verbal limitation.

Thing had sensors, data, and was location-aware. It also managed in part, the relationships between members of the household. This is what the authors would expect of an agent in a healthcare smart environment, and what the authors hope, within the range of sensitivity to privacy, might be achieved. Developers will have to think like Thing in order to take into account how to manage the multiplexed communications, needs and messages that come from multiple sensors and actuators at different locations within the healthcare environment. People, sensors or actuators might be moving within the environment requiring location awareness on the part of the overall environment to use the capabilities of the space. Physical spaces are gradually shifting, with the aid of pervasive technology, from being mainly locations or destinations (with space in-between), towards the notion of being places that ‘host transitions’ (Applin and Fischer, 2011a).

In healthcare, this becomes critical as people may move through many spaces as a result of what is required for their care. A patient might begin in one environ-

ment (doctor's office) and transition through the course of diagnosis or treatment through several more offices, labs, or specialty clinics, each for an unknown amount of time. No two patients may have the exact time or place experience as part of the process of their care. This makes provider-to-patient ratios difficult to estimate and creates an unpredictable system that when unified for a 'standard' patient, risks individualized care through poor design of over homogenization. However, smart environments that can keep track of individual needs, requirements, times, preferences and schedules, can be welcome additions to any healthcare system, if they are implemented in a way that promotes human agency and protects patient privacy. In other words, it becomes even more critical for developers to create agency-based aware systems and to design the algorithmic underpinnings of the healthcare smart environment to be useful, yet unobtrusive. Most critically, these new designs must integrate to work within existing legacy systems.

PERVASIVENESS AND POLYSOCIAL REALITY

When the authors examined the current state of the distribution of pervasive technology, they discovered that it permeates some areas, and barely covers others. As services by sensors and actuators becomes pervasive, human expectation, and some level of fusion with the systems that support sensors, will become more and more intertwined.

To smooth the transition for healthcare into a sensor/actuator services system, conflicts within its culture with regard to adopting and adapting new technologies must be resolved by those developing and deploying pervasive technologies. Technological practice that is 'marked' (e.g. unabsorbed) cannot be pervasive. Technologies becoming 'unmarked' (e.g. absorbed) into the 'unawareness' of daily life in a healthcare system, indicate successful technology acceptance (Applin and Fischer, 2011a).

Humans are constantly trying to communicate whether static or in motion or in proximity or distanced. When humans communicate with others they might talk through closed doors. They also often disrupt, interrupt and try their best to be heard and to listen. Digital mobile technology enables people to be in the same place at the same time, or not, and to be mobile or not. Due to time, space, and conceptual differences, people may not be in the same 'plane of reception' at the same time even if they share time and space coordinates. To the extent that people share common sources of information while interacting with each other, the greater their capacity to collaborate becomes. If humans share too few channels relevant to a common goal, there may be too little mutual information about a transaction to interact and communicate well collaboratively. Poor collaborative interaction can lead to further

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relational fragmentation with the potential to promote isolated individuation on a broad scale (Applin & Fischer, 2011b). By changing the means that humans use to manage space and time during their daily routines, developers can shift human experience from individuated, user experiences to enhanced sociability within a multi-user, multiple application, multiplexed messaging environment. In healthcare smart environments, there are multiple channels creating multiple communications, which may or may not be coordinated or multiplexed, and receiving multiple communications in kind that may or may not be synchronous, all while people may be moving through the environment. It can add up quickly to being overwhelming (Applin and Fischer, 2012a).

PolySocial Reality (PoSR) as a conceptual model of the global interaction context that emerges when use of the social mobile web and other forms of communication contribute significantly to instantiating intentions (Applin & Fischer, 2011b, 2012a). PoSR describes the aggregate of all the experienced 'locations' and 'communications' of all individual people in multiple networks and/or locales at the same or different times. PoSR is based upon the core concept that dynamic relational structures emerge from the aggregate of multiplexed asynchronous or synchronous data creations of all individuals within the domain of networked, non-networked, and/or local experiences (Applin & Fischer, 2012b).

Network and mobile communications tend towards message multiplexing that results in a PoSR messaging environment that goes well beyond the limitations of human physiological systems to directly engage (Applin & Fischer, 2012b). Thus, the interaction environment described by PoSR implies that there are great challenges in using upcoming technologies to improve the social integration of people and their environments, and the entropy associated with location-awareness combined with PoSR outcomes creates a complexity problem that might benefit from a particular kind of Artificial Intelligence (AI) agency to solve on an as needed basis. When environments have the potential to be 'social' (even between themselves as machine-to-machine) there exists a high potential for fragmentation (e.g. partial or complete isolation from ensuing social transactions) due to PoSR related multiplexing.

This type of messaging situation in healthcare can be critical and lead to fatalities if messages communicating urgent, specific care instructions are not received and acted upon in a timely manner. The capacity to parse multiple messages in location-aware healthcare environments is certainly possible, through sensors and processors, and collating that material and sifting through what is critical is where an integrative agent can contribute. This is where Thing excels as an agent, mostly based on knowledge of the situation, the requirements and specifications, and what is going on in context in real time; the capabilities of the healthcare environment in the present. There will need to be well considered somewhat transparent software

and hardware in order to design agents with the utility of ‘Thing’ to manage multiplexed communications, needs and relationships in the healthcare environment.

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Thing operates through observing, reasoning and then taking action. Thing’s observations and reasoning are based on knowledge of the humans in its proximity that it has gained over time through understanding and learning what type of tasks they require assistance with on a regular basis. Thing expands the agency of group members and greatly enhances their experience within their rather complex environment by acting as an agent on behalf of a wide range of different services and facilities the environment has to offer, connecting these to intentions of the group. In a healthcare environment, Thing would require trusted access (on an appropriate sliding scale depending upon patient healthcare needs) to learn about a patient in order to successfully assist it in the healthcare environment. Thing can transform a complex jumble of services into a successful technological context. The authors argue that successful technological contexts are those that people use to expand their agency outside that technological context proper; the technology expands their general capacity to choose. (Applin and Fischer 2013).

A Thing-agent might improve a healthcare smart environment by specifying some principles that Thing must satisfy. Foremost, the authors would argue that a Thing-agent can and will facilitate people exercising agency.

Agency is the capacity to make and execute nondeterministic choices intended to advance to a goal as events unfold. For example, humans exercise agency when deciding whether to turn on a light or to walk across a street to avoid a possible obstacle. Agency implies that agents’ future choices are not intrinsically fixed or stochastically predictable except on the basis of secondary principles of reasoning, such as rationality, cooperation or enmity.

In any given circumstance, people have a set of options upon which they could base choices. In many cases they will not be aware of some options, a situation that discovery might advance. In other cases, people will lack the means to usefully enact an option because of a lack of skill or knowledge, even though they are aware of it as an available possibility. In still other cases, options might not be available because the contexts within which these would be available, cannot be deployed. Agency is a direct function of how well people can exercise available options into choices. Agency can be expanded by making new options available by discovery or invention, or through supplying the knowledge and skill required to exercise an option. Agency can be reduced by removing options or the capacity to exercise

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options. We can measure the effective agency within a context relative to a given agent as a simple ratio, choices/options.

Often these options and corresponding choices are somewhat predictable due to the assumption of cultural and social frames for reasoning that will vary between people depending on social roles, relative power and specialist knowledge. High levels of predictability will be based on mutual understanding of the different points-of-view by each participant. Resolving most complex situations is not as simple as making a single choice or a simple sequence of choices.

Adaptive agency is the capacity to transform options into choices, sometimes through learning or skill, but most often through exchange with other agents, where each possesses knowledge and skills that can activate options on behalf of the other. Exchange can be direct or deferred and results in the establishment of social relationships between agents. The foundation of a social relationship requires a mutual presumption of agency on the part of the other; social relations require that each party assumes the other has some level of agency (Applin and Fischer, 2012b). One of the outcomes of this relationship is a process of negotiation between social agents to arrive at a mutually beneficial consensus that influences future choices.

If someone wanted to turn on a lamp, they would most likely try a wall switch, the switch on the lamp, check the plug, or in rare cases, depending upon TV exposure, clap their hands (Srinivas et al., 2004). An average person might not expect or anticipate that the person seeking illumination would put their head in the refrigerator to make use of its automatic light. However, humans can, and have made this choice at times. This is the difficulty in developing adaptive software for an Agent (Thing). Fixed decision tree choices are good, but do not have enough information within them to fully satisfy human agency. An environment, to be truly smart, must learn from the cumulative data within its realm to understand and guess what likely choices might be for a given agent and then facilitate or enact these on behalf of that agent.

The first principle of Thing Theory shown in Table 1 is that the Thing-agent operates as a meta-agent over the entire technology context, not as a sub-component. Our Thing-agent assembles capabilities (e.g. whether or not the refrigerator light is suitable as a lamp) that are extensible based on what subcomponents of the system happen to be available. What Thing can do is ultimately limited by the basic capabilities of various system subcomponents in combination with Thing's knowledge about these and how to combine capabilities to make new more context sensitive capabilities. To increase the Thing-agent's capabilities, more information from subcomponents must be shared. The third principle of Thing Theory is that the Thing-agent must be context aware and able to identify that different combinations of capabilities are available in different contexts, and have a corresponding capacity

Table 1. Principles and functions of the thing-agent

	Principle	Function
1	Thing-agent is meta agent.	Operates over entire context.
2	Thing-agent's capabilities are based on system subcomponents.	Thing-agent's capabilities of extension are limited by system subcomponents capabilities.
3	Thing-agent must be context aware.	Thing-agent must be able to identify different capabilities in different contexts and to select the most appropriate one to take action.
4	Thing-agent works with other meta agents.	Thing-agent works with other meta-agents to expand their capabilities when required. Shared permissions/context/ capabilities are required as is some transparency between other meta-agents.

to manipulate contexts (e.g. enact, repress, and aggregate) to ‘reveal’ new capabilities, many of which may be ‘innovations’ based on context discovery (invention). The fourth principle of Thing Theory is that a Thing-agent extends the capabilities of other meta-agents. In order for the fourth principle to work, the meta-agents (a social network of at least one Thing-agent and another meta-gent) must have some type of transparency or at least shared permissions for the exchange of capabilities and contexts. To describe or analyze such multi-agent systems in healthcare, developers must take account of the social as well as the individual behaviors of the agents as well (Dix & Fischer, 2011).

In implementing Thing theory in location-aware Smart Environments the authors argue that a Thing-agent must relate to other agents and interface between multiple smart technological contexts. At a minimum, the Thing-agent will inform agents of the capabilities of a Smart Environment in pragmatic terms that make sense to the agents, and ideally provides a high level interface for the agents into these environments (Applin & Fischer 2013).

The Thing-agent will discover the capabilities of the various systems it ranges over, and possess a representation of the pragmatic contexts for these. There is an inherent notion of extensibility; new features will be added and people (or other agents) will use these for many purposes not anticipated by designers. A Thing-agent could move forward on this problem by using an extensible multi-agent simulation incorporating a specification of the capabilities of each sensor and actuator, user expertise and other information, to create a model of the outcomes of how services and agents might interact with each other. Thing-agent could then offer reasonable choices to user agents in terms of what is likely to occur should the agent make a given choice (Applin & Fischer 2013: Conclusion).

IMPLEMENTING THING THEORY

There are two approaches to implementing Thing theory in healthcare smart environments: as an interface to user-agents; and as an interface between multiple smart technological contexts that may be using and supporting the same location. A Thing-agent must do both to be effective, where the Thing-agent serves at a minimum as a means to inform user-agents of the capabilities of the smart environment in pragmatic terms that make sense to the user-agents, and ideally provides a high level interface to these. The Thing-agent must be able to discover the capabilities of the various sub-systems it ranges over, and to possess a representation of the pragmatic contexts in which the capabilities are expressed. This must be done in a way to where Thing-agent facilitates choices by user-agents, rather than forcing user-agents into specific choices.

For most technology, the user-agent interface is designed by implementing a metaphorical interface. This works reasonably well for simple technological contexts, though it often takes a very long time for designers to find just the ‘right’ metaphor for implementation.

In a healthcare smart environment, there is usually the intent to ‘embed’ a technological context within existing contexts that people use. Thus, there is an inherent notion of extensibility in that new features can be added, sometimes arbitrarily with the assumption that people will use the environment for many purposes, not all of which can be anticipated by designers. A possible approach for resolving this is for Thing-agent to employ one or more extensible multi-agent simulations that incorporate a specification of each sub-system that specifies sensor information, associated services and the role of other agents, including health care professionals and patients, to project multiple hypothetical models of how the services and agents might interact with each other, and the resulting contexts that emerge from different combinations of interaction. This would provide a basis for Thing-agent to offer informed choices to both sub-system agents and user-agents, providing feedback in advance to them regarding the choices and the likely outcomes should an agent make a choice, thus permitting agents to ‘fine-tune’ how they proceed.

To achieve this, developers might need to move beyond classical imperative logics most commonly in use for inference-based systems. Deontic logic was originally developed to explore the logic of morality in theology. In addition to the classical predicate calculus, deontic logic adds two basic modal operators, permitted and obliged (and their negations). Rather than describing specific outcomes, deontic operators focus on potentialities such as what is permitted and not permitted at a given time, with the capacity to identify derivations that make the possible impossible, and the impossible possible. From an agency perspective, identifying available

options and choices, and in particular a means of analyzing what is needed to turn a theoretical option into a practical choice (Fischer, 2006).

Deontic logic has been demonstrated to be a useful basis for constructing simulations of sensitive real-time, time and location aware interactions between agents of different types (Ryan et. al. 1991; Dong and Li 2013). Casto and Maibaum (2007) present a deontic logic suitable for representing the interrelations between agents of different types, including agents exhibiting agency, and Horty (2001) is an extended logical treatment of representing and reasoning with agency in deontic logic. An advantage of modeling with deontic logic is that it is relatively easy to introduce new agents, new conditions and new outcomes into a working simulation and produce results that are instructive to user-agents.

Furthermore, a Thing-agent mediated multi-agent simulation can be useful for designing new pan-context technologies to be incorporated into the location-aware smart environment, since these too can take advantage of ‘simulation services’ provided by Thing-agent as a part of their decision making, both discovering new capabilities, contexts and a basis for comparing different options. Effectively this facilitates the incorporation of true agency into even sub-systems, and thus the capacity for the design of social cooperation between processes, rather than master-slave relationships, exploiting Thing-agent to ensure that the information that needs to be shared to support agency in the network of agents is available to maximize the capacity for cooperation, and avoid the problems that can arise from PoSR networks of cooperating agents.

A presumption might be made that a Thing-agent must have a human intelligence of sorts. The authors agree to the extent that social intelligence is human. However, research such as Brian Hare’s ongoing research on dogs, highlights their non-human anticipatory intelligence as a alternate type of sensory intelligence (Hare and Tomasello, 2005). A Thing-agent needs to resolve design principles and may need to do this in non-human ways, while remaining socially aware.

Patient Process Management Using Thing Theory

Extending the Kaiser and IBM example from the IBM Interconnect Smarter Processes Keynote in 2015 (IBM Software, 2015), one of many possible cases where Thing Theory could be used is as a solution to nurse-to-patient room ratio concerns. In the Interconnect example, nurse to patient ratios are shown to need to be maintained at 1:4 for optimum care in a hospital environment. The IBM/Kaiser solution proposed tracking nurses to trigger messaging systems, to direct available staff to rooms on wards with lower ratios. This tracking may cause privacy concerns for nursing staff and inhibit implementation. If the healthcare provider’s concern is insuring that patient needs are attended to, Thing-agents could monitor in-room processes at a

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sensor/process level and communicate those to negotiate with other Thing-agent representatives to summon staff.

One critical element of patient care is that the processes required to maintain that specific conditions of care, possibly unique to a single patient, are fulfilled. In the case of hospitalization, each patient may have different needs. Some may need oxygen, heart rate, fluid monitoring at close intervals, others may need different systems monitored or the same ones at different intervals. As people and their conditions are individualized, so must be their care. This is challenging to manage in an environment that must operate within constrained budgets and resources.

A new way to relate to patients using the IoT could be to understand patient care needs as time intervals and time functions that are different from each other. Computing gives developers tools to enable more sophisticated time management. A Thing-agent can manage the time schedules for each patient's needs and communicate those with other Thing-agents that manage nurse schedules. In this way, hospitals would not be tracking whether or not nurses were on the floor, but rather whether or not the maintenance tasks for individual care were addressed at the times they needed to be addressed. The sensors themselves on devices would respond to checks in place by physically present nurses, who would be available to check these patients due to the needs of the monitoring, rather than only due to needs of a nurse to patient ratio.

CONCLUSION

The healthcare environment intersects with people in deep and meaningful ways. To automate it without this consideration can be dangerous. The first steps of automation as applied to healthcare environments have been based on 'lean' and 'agile' principles with a first focus on cost-savings. This is a short-sighted implementation plan that does not account for the long-term effects on patients of losing agency and critical relationships. Lean and agile mechanisms for 'processing' patients have neglected to respect patients' privacy and have risked patient safety as healthcare workers scramble to make their quota of rooming patients in a lean healthcare environment. Future plans of healthcare providers to incorporate remote 'video medicine' as further cost savings, have the possibility to impact patient care as doctors may miss a critical diagnosis due to the loss of resolution in a small video window. Furthermore, the condition of 'denial' can impact the accuracy of patients self-reporting their states.

When IoT is applied to healthcare the outcome will be multiple partially-automated IoT device-based systems, from different vendors that vary from installation to in-

stallation. These systems will depend on other systems (and people) for oversight, information and activities required for proper operation in any specific context. These systems will have to work together without being designed specifically to do so. In terms corresponding to the four principles of Thing Theory (Table 1), we will need a supervisor agent that operates over the entire context. This agent will monitor dynamically the capabilities and requirements of each IoT device system in the context. It will identify appropriate applications of these capabilities as specific and unique circumstance transpire, coordinating all the systems in that context through relevant information and judgements in the context of use.

Thing is, however, just a critical element, not the only element needed for successful IoT applications in healthcare. In short, automation without context, agency and consideration for patients will lead to unforeseen complications that will cost much more in the long run to resolve. Technology that inhibits a physician from developing the trusted relationships critical and foundational to good care, can also create similar problems. The people designing and implementing healthcare systems must see the people within the systems (workers, physicians, and patients) as a series of long-term relationships that are to be managed, not necessarily resources, services and supplies to be coordinated in the moment. Much of what makes a good doctor-patient relationship function well is the understanding and shared history that happens between the doctor and patient over time. IoT technologies can augment relationships by being smarter about how information may be gathered and processed, but it is best to do this within the context surrounding existing and well-established relationships within the healthcare system. Humans do not necessarily benefit from solely interacting with machines in this context. However, machines can provide processing and knowledge management that assists and bolsters relationships. Our recommendation is that clinics understand how to augment their offerings to let machines do what they do best in the context of enabling the people within the system to do what they do best: create, build and sustain human relationships in the context of maintaining overall health and well-being.

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KEY TERMS AND DEFINITIONS

Asynchronous: Not occurring in the current time. Voice mail is an example of an asynchronous message.

Heterogeneity/Heterogeneous: Composed of many different pieces, parts or attributes.

Location-Aware: A condition by which technology can track its location in an automated fashion using a combination of hardware, sensors, and software.

Meta-Agent: A software algorithm that can monitor various inputs from various lower level hardware sensors and their data outputs.

Multiplexed: A telecommunications term referring to a circumstance where multiple signals, message streams or data, are combined into one signal that is transmitted over a shared medium.

PolySocial Reality: A conceptual model of all synchronous and asynchronous communications by humans/humans, humans/machines, machines/machines, animals/animals, animals/humans, animals/machines.

Smart Environment: An environment that contains responsive electronic monitor equipment such as sensors, actuators or other devices that can measure information in the environment and act upon it to either generate, share or transmit data to enable reactions from the environment or devices related to the environment.

Synchronous: Occurring in real time in the present. People meeting face-to-face are doing so in synchronous time.

Thing-Agent: A trusted meta-agent that manages low level processes in a smart environment and brokers preferences to other trusted meta-agents.

Chapter 10

Social Internet of Things in Healthcare: From Things to Social Things in Internet of Things

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ABSTRACT

This chapter presents a future vision for healthcare, which will involve smart devices, Internet of Things, and social networks, that make this vision a reality. The authors present the necessary background by introducing the Social Internet of Things paradigm. Agent technology seems to be a promising approach in the adoption of the Social Internet of Things in collaborative environments with increased autonomy and agility, like healthcare is. Also, it is examined challenges to the adoption of the Social Internet of Things in healthcare in order to facilitate new applications and services in more effective and efficient ways.

INTRODUCTION

The healthcare industry is constantly bound to adapt to the many occurring changes, from advances in diagnostic and therapeutic procedures to the most advanced information technology, in order to increase the overall quality of patient care, and also to reduce healthcare costs (Riazul Islam, Kwak, Humaun Kabir, Hossain, & Kwak, 2015).

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Various worldwide surveys conducted in relation to this field reveal that one of the biggest current technological initiatives in the healthcare industry is the Internet of Things (IoT) (IoT to Revolutionize Healthcare, 2015; State of the Market, 2015). In recent times, there has been a growing interest in building Social Internet of Things (SIoT) (Atzori 2011a, 2012, 2013).

This chapter examines challenges to the adoption of the Social Internet of Things in healthcare in order to facilitate new applications and services in more effective and efficient ways. Several papers and studies have focused their attention on this new paradigm. We present the necessary background by introducing the SIoT paradigm. Subsequently, we provide a survey of the applications of SIoT in different domains. Some solutions for SIoT are also presented, each with its own strengths and weaknesses. We consider various enabling technologies that could be exploited in order to extend the current applications in the healthcare area. The movement of healthcare out of the hands of healthcare providers (hospital, laboratory, etc.) and into people's homes will be greatly facilitated with the latest remote sensing devices of all kinds connected to physicians and care givers. The examples are numerous and the potential for cost savings and improved care is overwhelming. We also address social networks that can be used for storing and sharing information of interest for the SIoT interactions. Agent technology seems to be a promising approach in the adoption of the Social Internet of Things in collaborative environments with increased autonomy and agility, like healthcare is. If a physical entity is linked via a unique identifier to an agent, then the identifiable entity could be easily integrated in SIoT as a social thing. For things in SIoT to understand each other, sharing a common understanding of the structure of information among them is required. Ontologies offer a solution to represent information, including the relationships between things in SIoT and to share knowledge as well. Moreover, ontologies allow the dynamic integration of knowledge in different domains into SIoT. Finally, we highlight the lessons to be learnt from the past, open challenges and some possible directions for future research.

This chapter is organized as follows: background of research fields of Internet of Things and Social Internet of Things is investigated in the second section. The next section presents the enabling technologies that could be exploited in order to extend the current applications in the healthcare area. Next, some consideration related to evolution of medicine models and potential implications of SIoT adoption in healthcare are presented. Next section presents some practical benefits enabled by SIoT for people suffering from asthma. Finally, future research direction and conclusions are pointed out.

BACKGROUND

According to various studies, e.g. (Davis, 2004; Fisher, 2003), healthcare systems around the world, face rising costs and uneven quality, thus generating significant variations, both within the United States and internationally. It is a common fact that U.S. adults often do not receive the proper level of care recommended for a certain condition. One study indicates that on average, individuals received only about 55 percent of the recommended medical care for common illnesses (McGlynn et al., 2003), whereas preventive care is often overlooked.

But various studies reveal that a large number of people tracks health indicators or symptoms for themselves or for someone else. For example, according to (Health Fact Sheet, 2015), 60% of U.S. adults track their weight, diet, or exercise routine; 33% of U.S. adults track health indicators or symptoms, like blood pressure, blood sugar, headaches, or sleep patterns; 12% of U.S. adults track a health indicator on behalf of someone they care for. The technology offers the potential to help people to track all these data. For example, according to (Susannah, & Duggan, 2012), 31% of cell phone owners, and 52% of smartphone owners, have used their phone to look up health or medical information. Thus, the advancements in technology, like Internet, Web-based, smartphone, etc. have encouraged the development of technology-based applications aimed at supporting people in both easily tracking health indicators or symptoms, and diagnosing and managing various diseases.

A report by PwC's Health Research Institute (HRI) reveals patients' attraction to social media sites such as Facebook and Twitter in order to find and share medical information (Social media, 2012). According to this survey of 1,060 U.S. adults, about one-third of consumers are using the social space as a place for healthcare discussions. And 42% of consumers have used social media to access health-related consumer reviews. 72% of Internet users say they looked online for health information within the past year, according to (Susannah, & Duggan, 2013) and 27% of US internet users had tracked health data online, (Health Fact Sheet, 2015). Consequently, in trying to reduce the costs of providing care and to increase efficiency, many healthcare organizations adopt a social media oriented strategy in order to interact with patients and provide them services and information that could impact their healthcare decisions.

Current development of the traditional medical model toward P6 medicine model can be amplified by the Internet of Things (IoT) paradigm.

The Internet of Things (IoT) infrastructure allows connections between different entities (i.e., human beings, wireless sensors, mobile robots, etc.), using different

but interoperable communication protocols and makes a dynamic multimodal/heterogeneous network. In this infrastructure, these different entities (viewed as “things”) have the ability to discover and explore one another, gather, provide, or transmit information to IoT. Thus, according to (ITU Internet Reports, 2005, p. 8), “from anytime, anyplace connectivity for anyone, we will now have connectivity for anything”, not only for anyone. According to (Botterman, 2009, p. 5), the Internet of Thing integrates “things having identities and virtual personalities operating in smart spaces, using intelligent interfaces to connect and communicate within social, environmental, and user contexts”. And, “from objects that communicate to objects that socialize in the Internet” (Iera, 2011), there is only one step. Thus, a novel paradigm of the Social Internet of Things (SIoT) was introduced: a “social network of intelligent objects” that is “based on the notion of social relationships among objects”, according to (Atzori, Iera, & Morabito, 2011b).

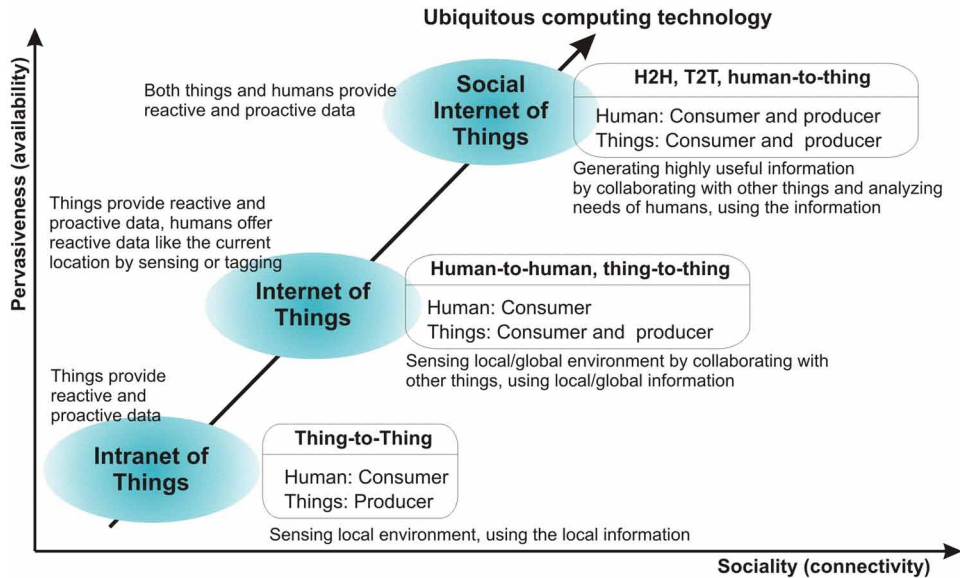
The authors of (Zorzi, Gluhak, Lange, & Bassi, 2010; Uckelmann, Harrison, & Michahelles, 2011; Ortiz, Hussein, Park, Han, & Crespi, 2014) present a phased approach of the evolution of Internet of Thing from Intranet of Things or of Extranet of Things to Social Internet of Things. They also discuss how the situation of many “Intranets” of Things should evolve into a much more integrated and heterogeneous system, namely the Internet of Things. According to (Ortiz, Hussein, Park, Han, & Crespi, 2014), “IoT enables the creation and composition of new services and applications, offering to individual users a new ecosystem where different intranets of things can collaborate”. Also, “things should be socialized for allowing humans to establish relationships with them in an easy way”. In the same paper, the authors present visually the evolution of IoT from Intranet of Things to SIoT (Figure 1), considering that “the cluster between Internet of Things (IoT) and social networks (SNs) enables the connection of people to the ubiquitous computing universe”.

The Internet of Things is viewed as an evolutionary process, rather than a completely new one. And the Social Internet of Things, dealing with some IoT related issues, is part of evolution. According to (Atzori, Carboni, & Iera, 2013, p. 13), “the driving motivation is that a social-oriented approach is expected to put forward the discovery, selection and composition of services and information provided by distributed objects and networks that have access to the physical world”.

According to (IoT to Revolutionize Healthcare, 2015) the range of “things” that can be part of an IoT or a SIoT solution is practically unlimited. From the small and simple to the large and complex, the possibilities are enormous. Next we present some medical monitoring devices that can be connected to IoT or SIoT in order to improve the overall quality of patient care.

Figure 1. Evolutionary history

Source: Ortiz, Hussein, Park, Han, & Crespi, 2014.



State of the Art of SlOT Enabling Technologies

Medical Monitoring Devices

Common to everyday living, wearable and wireless implantable medical devices, as well as home monitoring devices, are endowed with transmitting capabilities (Natarajan, Prasath, & Kokila, 2016) that make information about a patient available for hospital staff analysis. For example, these devices may be wireless interconnected with sensors that measure the glucose level, the heart rate, the blood pressure, the weigh, and other medical parameters. These characteristics will turn these devices into a real part of IoT. In this sense, various applications are currently deployed, especially regarding the measurement and monitoring of a patient's vital signs, including glucose level sensing, electrocardiography, and blood pressure monitoring.

Glucose Level Testing/Glucose Monitoring

It is a common fact that carbohydrates are the main sources of glucose, essential for providing energy for both the brain and the body. Nevertheless, a high level of blood glucose over a prolonged period of time might cause diabetes. The World Health

Organization estimates that more than 380 million people are suffering from this disorder, and these figures will double by 2030 (What is Diabetes? (n.d.)).

During the last decade, several non-invasive methods for glucose monitoring were used. For example, in 2003 Caduff et al. (Caduff, Hirt, Feldman, Ali, & Heinemann, 2003) described an experiment using a new, non-invasive, non-optical continuous glucose monitoring system, based on impedance spectroscopy. Later on, they used a multisensor system, combining sensors for dielectric and optical characterization of skin (Caduff et al. 2009). In 2006, the concept of Continuous Glucose Monitoring (CGM) was introduced (Hovorka, 2006). Actually, blood sugar levels are recorded using a CGM sensor implanted under the skin of a diabetic patient, and that sends information to a wireless device. In 2011, Istepanian et al. (Istepanian, Hu, Philip, & Sungoor, 2011) proved the potential of Internet of m-health Things “m-IoT” for non-invasive glucose level sensing. Looking towards the future 4G health applications, this concept embedded both m-health and IoT functionalities.

Many companies have developed CGMs using Bluetooth technology to transmit glucose levels to a compatible smart device (i.e. Medtronic, Dexcom, Glucowise). In 2014, Google and the Swiss health care group Novartis announced that they were testing a smart contact lens able to measure the glucose level from tears. Therefore, a new way to deal with diabetes would be to endow such lenses with transmitting capabilities. Also, BodyTel from Germany sells a Bluetooth 4.0 device with a blood glucose meter (GDH-FAD, n.d.) that communicates with Android and iOS smartphones, and transmits data to a medical data cloud.

Electrocardiogram Monitoring

Electrocardiography (ECG or EKG) is a diagnostic tool which records the electrical activity of the heart over a period of time. The electrocardiogram is not used only to measure the rate and rhythm of the heartbeat, but also to diagnose different diseases like arrhythmia, ischemia etc. ECG is very important, especially for the evaluation of patients with possible heart problems.

The Belgian company Imec developed a Smart ECG necklace used to monitor every-day cardiac activity (Wearable health monitoring, n.d.). The device is based on a commercial low-power microcontroller and a low-power radio, and has wireless communication capabilities within 10 m range. Also, the company designed a prototype which stores heart rate and 3D accelerometer data. These data can be transmitted in real time to a receiver located up to 16 km away from the acquiring point.

The Spanish start-up Nuubo, dealing with wearable medical devices for cardiac prevention, diagnostics, and rehabilitation solutions developed a wireless and remote

cardiac monitoring platform based on a biomedical e-textile technology - BlendFix Sensor Electrode Technology (NECG Platform, n.d.).

Also, some researches are related to ECG and IoT (Li, 2014; Lu, 2015).

Blood Pressure Monitoring

Researchers and companies showed interest in developing blood pressure devices for IoT integration. In (Xin, Min, & Ji, 2013) the authors proposed an IoT - based blood pressure monitoring system (patent in China), their intelligent terminal being based on the Internet of Things and including the following: a health monitoring device, a data communication device, a locating device, a microprocessor, a storage device, an input-output device, and an electrical power unit.

Many authors implemented various applications for blood pressure monitoring, based on different transmission technologies, usually Bluetooth or Zigbee (Antonovici, 2014; Anurag, 2014). For example, the authors in (Hassanalieragh et al., 2015) use a concentrator to access each individual sensor from an IoT-based architecture.

Different companies released blood pressure monitors that not only check the readings, but also automatically store data in the cloud. For example, QardioArm implements a “tap to pair” system with iPhones and Android, working on Bluetooth 4.0 technology. Data are automatically stored in the Qardio cloud and then shared by actors from the health system or the family.

Aiming to improve the patients’ blood pressure, Withings Company and the American Medical Group Foundation finished in 2016 a pilot project (Macala, 2016) that used the Withings Wireless Blood Pressure Monitor. This monitor is connected with the patient’s personal iOS or Android device and collected data are transmitted in real time to his personal healthcare team, through a dedicated web portal. Using this device, patients are able to monitor and control their own blood pressure and the medical staff is provided with valuable information regarding the health status of a large group of patients.

Body Temperature Measurement

Body temperature is one of the four main vital signs that must be monitored to ensure safe and effective care (McCallum, & Higgins, 2012). Body temperature sensors are used as a part of various items: wearable bracelet, smart pillow, finger-style device, skin stamp, etc.

Authors in (Mansor, Shukor, Meskam, Rusli, & Zamery, 2013) proposed a remote health monitoring system in which such a sensor sends the body temperature values to a microcontroller through an Xbee wireless communication. Real-time data are stored in a health monitoring database, using a wireless local area network.

Another temperature monitoring system was found in (Malhi, Mukhopadhyay, Schaeffer, Haefke, & Ewald, 2012). Here, the authors designed and developed a smart noninvasive wearable physiological parameters monitoring device based on Zigbee technology. The deficiency of Zigbee protocol stack is that it might prove too large to handle. Therefore, other authors (Chin, Atmodihardjo, Woo, & Mesbahi, 2015) decided to use the MiWi protocol stack instead. The advantages derived from using this protocol consist in reduced code size, small footprint, and a very low overhead, in comparison to the ZigBee protocol. Authors in (Jian, Zhanli, & Zhuang, 2012) use a OSGi (Open Service Gateway Initiative) to send packages with the body temperature values into an M2M (Machine to Machine) format.

Wireless Body Temperature Monitor from Win-Health is a technologically advanced medical device which allows body temperature recording up to 100 hours. It consists of 2 independent parts: a transmitter, and a receiver; the transmitter monitors the body temperature and transmits the values automatically to the remote receiver.

The US start-up MC 10 released a high-tech tattoo (actually an elastomeric plaster which includes an electronic part) endowed with measuring capabilities (Bachfischer, 2014). It can be used not only to monitor the body temperature in a real-time manner, but also to measure some biometric data (brainwaves, heartbeat, and muscle activity).

All these above presented devices are a few examples from a large range of suitable candidates to “things” that could be connected in IoT/SIoT.

Social Internet of Things

The goal of the Internet of Things is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service (Vermesan, & Friess, 2014).

According to the authors of (Atzori, Iera, & Morabito, 2011b, p. 1193) “the IoT vision can be fully achieved only if objects are able to cooperate in an open way”. Thus, in order to exploit the potential of the IoT, the authors believe that trust objects and provided services should be easily discoverable and usable by humans and by other objects. But, the existing solutions for service discovery in IoT do not scale with the number of things that are expected to be connected in IoT. Moreover, although researchers reveal other problems for adopting IoT in reality, various solutions were proposed. In this chapter, we will focus only on the potential offered by social networking to enable IoT.

In (Kleinberg, 2008) the author noticed that the exponential growth of social networking websites usage, along some of the features provided, have attracted the attention of a large number of researchers from various areas. For example, several authors focus on the great potential of using online social networks for enhancing

the Internet search (Mislove, Gummadi, & Druschel, 2006; Erola, Castellà-Roca, Viejo, & Mateo-Sanz, 2011), for enabling new forms of information exchange in the Internet (Mislove, Gummadi, & Druschel, 2006), or for optimizing the peer-to-peer networks (Fast, Jensen, & Levine, 2005).

In the last years, social relationships between human beings were extended to social relationships between objects, as solutions to various problems. The authors of (Holmquist et al., 2001) were among the first to tackle with the socialization between objects, and they presented a solution for establishing qualitative relations and selective connections between smart wireless devices. In their paper, the authors analyzed temporary relationships between objects and how the owners of those objects should control such a process in the context of ubiquitous computing. In 2001, when the paper was published, both concepts of the IoT and the online social networks were in their beginning stages.

More recent literature focus on several research projects and experimental applications based on a new generation of objects. For example, Bleeckerin (Bleecker, 2006), introduces the neologism “Blogject”- ‘objects that blog’ in order to distinguish the “things” connected to the Internet from the “things” participating within the Internet of social networks. The researcher presents in his paper the characteristics of Blogjects: they can “track and trace where they are and where they’ve been”; “have self-contained (embedded) histories of their encounters and experiences; “have some form of agency — they can foment action and participate; they have an assertive voice within the *social web*”.

In fact, the Blogject is viewed as a kind of early ancestor to the Spimes, defined by Sterling in (Sterling, 2005) as material instantiations of an immaterial system, digitally manufactured things from virtual plans, trackable in space and time.

Later on, P. Mendes (Mendes, 2011) presents objects able to participate in conversations that were previously reserved to humans only. “Such objects may be intermittently connected most of the time, and may be capable of collecting and processing data without a constant human intervention. The result is a self-organised ecosystem able to make useful data available to people when and where they really need it, augmenting their social and environmental awareness”.

With the rapid development of social networking, researchers focused on the benefits social networking could bring to IoT.

D. Guinard et al. (Guinard, Fischer, & Trifa, 2010) proposed the use of the existing online social structures as a solution for enabling the sharing of things in the context of the IoT. Thus, exploiting various features offered by social networks (e.g. Facebook, LinkedIn, Twitter, etc.) and their (open) APIs, the authors build a system for sharing and controlling access to resources supplied by a given Web-enabled device (smart thing).

In order to analyze the behaviors of objects and people as data, L. Ding et al. (Ding, Shi, & Liu, 2010, p. 417) propose a platform to cluster together the Internet, the Internet of Things, and social network. Thus, “since the development of the Internet of Things, objects are involved into the network together with people” they consider that the “social networks can be built based on the Internet of Things” and “are meaningful to investigate the relations and evolution of the objects in the IoT”.

In 2010, M. Kranz et al. (Kranz, Roalter, & Michahelles, 2010) present in their paper an investigation regarding both the potential of combining social and technical networks and the implication of so-called “socio-technical networks” in the context of the IoT. Also, the authors describe how to empower physical objects to share pictures, comments, and sensor data via social networks. However, they do not propose any solution for the required architecture and protocols or for how the objects involved can establish social relationships.

Authors of L. Atzori et al. (Atzori, Iera, & Morabito, 2011) define various types of relationships in which things can be engaged: Parental Object Relationship (POR) (built in same period, by the same manufacturer); Co-Location Object Relationship (CLOR) (exist in a common location - cohabitation); Co-Work Object Relationship (CWOR) (work in a common location); Ownership Object Relationship (OOR) (belong to the same owner); Social Object Relationship (SOR) (objects that come into contact due to owners relationships). Based on this last relationship among objects, the paper introduces the concept of Social Internet of Things (SIoT). Moreover, considering a comparison with Social Networks Services (SNS) for human beings, the authors introduce an architectural model of SIoT and imagine some possible application scenarios where objects share best practices. Thus, for example, they propose to establish social relationships between PCs in the same local area network in order to “find solutions to common setting problems, such as those related to the configuration of a tricky network printer”. Similarly, social relationships established between devices that visit the same geographical area allow the exchanging of useful information on the physical world. In this scenario, the authors consider the case of handsets that provide data on the radio coverage to new visitors so as improve their connectivity service.

According to L. Atzori et al. (Atzori, Iera, & Morabito, 2011), trustworthiness of the billions of members of the IoT should be a key element in object selection and provided services usage. The problem of the trustworthiness in the Social IoT (how to know which services and objects to trust) is addressed by the authors of (Nitti, Girau, Atzori, Iera, & Morabito, 2012; Nitti, Girau, & Atzori, 2014). In order to build a reliable system on the basis of the behavior of objects, the authors focus on understanding how the information provided by members of the social IoT has to be processed so as to avoid attacks and malfunctions. Therefore, they defined and analyzed two models for trustworthiness management in the social IoT: the subjective

and the objective models. The authors plan to use the trustworthiness management, in order to enable the promoting social relations in the social IoT.

The authors of (Nitti, Atzori, & Cvijikj, 2014; Nitti, Atzori, & Cvijikj, 2015) address the problem of network navigability in the Social Internet of Things. In order to find the right object that can provide a desired service, an object can use its own relationships, the friends of its friend, and so on. Considering the selection of the friendships as a key for finding the desired service and, consequently, for a successful deployment of the SIoT, the authors focused on the selection of a narrow set of links, in order to support an efficient management of friendships. Also, they analyze possible strategies for the benefit of overall network navigability.

In (Girau, Nitti, & Atzori, 2013), the authors analyze the major IoT implementations, highlighting their common characteristics that could be re-used for implementing a new platform for the Social Internet of Things. Also, the authors present the major extensions introduced on the existing platforms, in order to offer the features of the SIoT. They describe some possible simple application scenarios that use this platform, “where objects create their own relationships and groups, in order to provide several functionalities to the final users” (p. 5), with minimal human intervention.

Social Internet of Things Platforms

Even though in recent years different models and prototypes of SIoT occurred, practical applications are not very present in literature. Ascribing social attributes to connected devices will open new ways to develop a new generation of applications where human-to-device social relationships will be intensively exploited.

Some examples of SIoT platforms are briefly described below.

Cosmos

Cosmos is an IoT platform, developed in a FP7 project. The declared aim of COSMOS is to “enhance the sustainability of smart city applications by allowing IoT based systems to reach their full potential” (“Cultivate resilient,” 2015). The authors proposed this platform in order to endow things with the capacity of acting in an autonomous way, while they become smarter and more reliable. Three representative scenarios were considered in COSMOS: Smart heat and electricity management (London), Smart mobility for public transport (Madrid), IoT Business Eco-System (Taipei). Virtual entities (VE) were used to represent things and groups of things from the real world. VEs act with specific goals and internal mechanisms to achieve them. Multiple interactions between VEs can be established for sharing a common goal, for achieving specific objectives, for advertising properties/attributes actualization service offers etc. (Voutyras, Bourellos, Kyriazis, & Varvarigou, 2014). Further on, the authors considered the social relations and interactions between VEs and

introduced two new COSMOS components: Social Monitoring and Social Analysis (Voutyras, Gogouvitis, Marinakis, & Varvarigou, 2014). The first one collects, aggregates, and distributes monitoring data towards collaborating groups, while the second one extracts the VE complex social characteristics, constructs models and patterns for VEs' behaviors, and establishes relations between them. This way, COSMOS became a SIoT platform since, based on social media technologies, it exploits social relations and interactions between the VEs. The result is an interesting social concept: friendship between VEs. Social criteria are used for friends' choice and a valuable advantage of this platform is that each VE is in a relationship of mutual aid with other VEs. Other advantages lie in the possibility of applying this concept to many areas, such as eHealth, environment monitoring, security & emergencies, traffic management, logistics, industrial control, home automation, etc.

ThingsChat

This platform was a subject of a doctoral thesis (Han, 2015). The author considered that connected devices are able to have social relationship with both people and other devices. In this approach, a Web API was used to assure the interaction between online social network (OSN) and devices. Later on, new functionalities were added to the OSN core, and the result, an universal OSN of everything, was named ThingsChat. To include social characteristics into the service framework, a Device Socialization module was added to the architecture presented in (Han, 2015). This module facilitates communication between both devices and SIoT, and devices and human users. A home gateway named ThingsGate is the element that discovers, stores, and transmits device services to ThingsChat. This module is responsible with user grant authorization to ThingsChat and device initialization with social functionalities. In this way the connected device become social entities. ThingsGate plays a vital role in the realization of the socializing device, very important for this platform. In order to fit the device in the SIoT platform, ThingsGate acts like a mediator in the process of device authorizing and customization. It is the module that registers the device in SIoT and adds it to the socialized list, which can be accessed later by user. Message exchanges between users and devices are facilitated by existence of a NLP (Natural Language Processing) interface which converts user messages into machine readable commands, and vice versa. The typical interaction between users and devices identified by the author is that the user asks the device to complete various operations and the device does the job and afterwards replies back to the user. This seems to be similar to the client/server negotiation process in multi-agent technology. Otherwise, we consider that some of the functionalities on/ in this platform could be realized by using agents (for example, NLP).

Socialite

For bringing to reality the vision of the SIoT, the authors of (Kim, 2015; Kim, 2016) propose a cloud based distributed collaboration framework, named Socialite. As the

authors presented, the Socialite architecture is designed to support the following: the interoperability of different connected devices from various manufacturers performing in different ecosystems; the scalability to handle a large number of data streams from various interactions between devices and/or people; the extensibility, by taking into consideration future devices to be connected and, also, provided services, for achieving the proposed goals based on different types of social relationships. In order to allow participants in Social Internet of Things to collaborate with each other in this framework, the authors define new social relationships between humans and devices, in addition to existing friendships among users in social networks (Kim, 2015; Kim, 2016):

- **Collocation:** Users and/or devices in “the same” location.
- **Friendship:** Relationship between users, as in Social Networks.
- **Kinship:** Devices with a same model and manufacturer.
- **Ownership:** A device registered by its owner.
- **Shared Ownership:** Devices owned by a same user.
- **Thriendship:** Friendship among things/devices of friends.

These newly defined social people-to-device and device-to-device relationships could be used in order to determine how the data generated by users and devices is being exchanged, distributed and received.

The uniform access to different connected devices and people in the system is enabled by the semantic models defined in this framework for users, locations, relationships, services and devices.

Multi-Agent Technology in Healthcare, IoT, and SIoT

In order to solve various problems related to information exchange between different things connected to IoT, agent technology proves to be a viable solution. Before presenting the specific aspects of the problems solved with the help of this type of technology, we briefly introduce the agent technology and several systems developed for healthcare.

There is no universally accepted definition of the term *agent*. However, the definition given by Wooldridge is one of the most comprehensive and frequently used worldwide. According to it, an agent is “a hardware or (more usually) a software-based computer system that enjoys the following properties: autonomy - agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state; social ability - agents interact with other agents (and possibly humans) via some kind of agent-communication language; reactivity- agents perceive their environment and respond in a timely fashion to

changes that occur in it; pro-activeness - agents do not simply act in response to their environment, they are able to exhibit goal-directed behaviour by taking initiative” (Wooldridge, & Jennings, 1995). The multi-agent system (MAS) paradigm views agents mainly as cooperating entities acting in a group with other agents in order to solve various problems. To enable agents to interoperate ontologies are part of solution. Ontologies represent a formalism which allows the representation of the knowledge related to a certain field, as a model. “Ontologies can be used to represent the structure of a domain by means of defining concepts and properties that relate them” (IGI-GLOBAL Dictionary, 2016).

In fact, researchers agree that agent-based system technology provides a real paradigm for designing and implementing software or integrated systems that offer solutions to various complex and dynamic problems from different domains.

Over time, several multi-agent systems were developed in order to address some of the issues related to various domains, including healthcare.

Remote health monitoring solutions offer great potential help for the disabled, elderly and/or chronically ill patients. This way they have access to good healthcare without regularly visiting their doctors. Over time, various multi-agent systems that offer solutions to remote health monitoring have been developed worldwide.

A multi-agent system for remote healthcare monitoring through computerized clinical guidelines was developed in the SAPHIRE project (Laleci et. al., 2008). This system provides a Clinical Decision Support system for remote monitoring of patients at their homes, and at the hospital to decrease the load of medical practitioners and also of healthcare costs. Also, the system aims to reduce human error in hospital events/complications and finally to provide a feedback system for the medical staff in training.

K4CARE, (K4CARE, 2008), was a research project whose main objective was to create, implement, and validate a knowledge-based healthcare model for the professional assistance of senior patients at home. The main step of the project was to develop a healthcare model to guide the creation of an integrated system of healthcare services for the care of the elderly, the disabled persons, and the patients with chronic diseases, (Bergenti, & Poggi, 2009). The model created during this project defined the actors in the care model (representing the profiles of the subjects involved in the K4CARE model: healthcare professionals, patients and relatives, citizens, and social organisms), their roles and interactions. The concepts behind the model were formalized using ontologies and the chosen language for the ontologies was the OWL (Web Ontology Language).

Also, in the healthcare sectors, various medical systems that cooperate with each other were suggested. Thus, in (Iantovics, 2010), the author proposes a cooperative medical diagnosis multi-agent system called CMDS (Contract Net Based Medi-

cal Diagnosis System). This system can flexibly solve a large variety of medical diagnosis problems.

Moreover, the use of agents for gathering the patients' medical electronic records from the information systems of different medical units was addressed in many research papers.

In (Chen, González, Zhang, & Leung, 2010), the authors conducted a study about a secured scheme based on mobile agents, for the systems which manage electronic medical records. The medical staff can instantaneously search for complete information about a patient, by accessing his/her electronic records via the Internet. The mobile agents are used to search for the patients' electronic records in different medical units that provide medical services. Taking into account that a mobile agent communicates with other applications and agents from the network for a faster access to the medical information, the probability of security issues arising is very high. In order to solve the security problems, the authors use a management scheme for access keys based on the interpolation formulas of Lagrange and on hierarchical management structures to increase the security of mobile agents.

In order to gather the information distributed among healthcare centers, authors of (Martin-Campillo, et al., 2009), also take into account the use of mobile agents. The agents developed in the MedIGS system collect all the medical data about a patient by performing a local search at each hospital, part of a predefined group, avoiding the need for a central repository.

Given the different standards used to store the patient's medical records in various health care settings, the use of the ontology is mandatory in order to gather health-related information from many health information systems. The authors of (Chang, Yang, & Luo, 2011), go a step further and "propose an ontology-based agent generation framework for information retrieval in a flexible, transparent, and easy way on cloud environment".

To sum up, we can say that multi-agent technology proves to be a viable solution to various problems encountered in global health care.

Also, the semantic interactions and the interoperability between various things connected to the IoT could be achieved by using a multi-agent system. The adoption of a multi-agent system for an IoT oriented solution is enabled by a natural mapping between a real world entity and an agent. Hence, if a physical entity is linked via its unique identifier (e.g., Radio Frequency IDentification: RFID tag) to an agent, then the identifiable entity could be easily controlled in a complex network of autonomous objects. The distributed software agents will represent the desired IoT things and interact accordingly with the standard defined by the Foundation for Intelligent Physical Agents (FIPA).

Agent technology seems to be a promising approach in the implementation of the Internet of Things in collaborative environments with increased autonomy and

agility. Regarding the architecture of an IoT oriented solution, the benefits of an approach based on multi-agent systems (instead of using centralized approaches) are listed below:

- The multi-agent system can work even if one agent (as a component of the system) fails or is compromised;
- It is easy to recover a failed agent or replace it with another one;
- Autonomous agents are less vulnerable to attacks than in a centralized architecture.

But, considering the multiple advantages provided by the agent technology, researchers try to adopt it in implementing the Social Internet of Things. Currently, worldwide there are few applications of the Social Internet of Things using agent technology. Subsequently, we will take a look at some recently published research papers dealing with the adoption of multi-agent technologies in the Social Internet of Things.

Thus, Ciortea et al. (Ciortea, Boissier, Zimmermann, & Florea, 2013) propose to model the autonomous entities in the SIoT as autonomous and proactive agents. The authors' aim is "to enable things as proactive participants in existing social networking services" (p. 1536), extending and transforming social networks by integrating autonomous and proactive things.

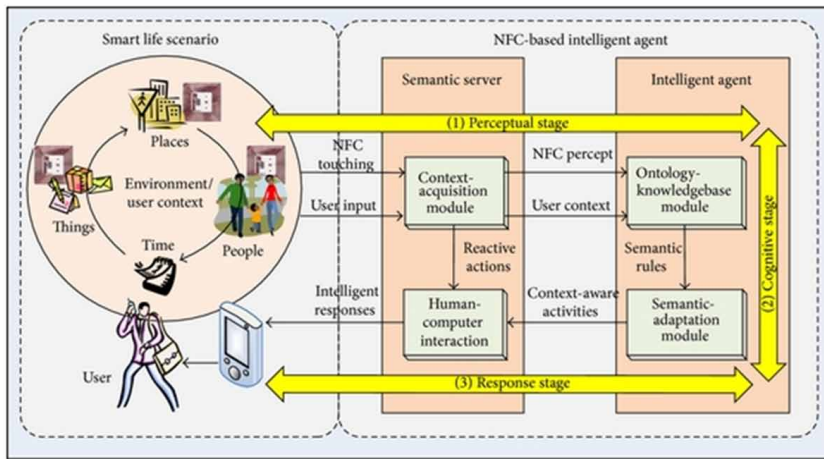
The authors of (Hussein, Soochang, & Crespi, 2015) propose a framework for adaptive and personalized smart services provisioning within the Social Internet of Things. Built on the socio-technical networks, it was considered as goal-driven, i.e. cognitive, context-awareness being the core for intelligence generation. The presented results show reduced overhead of contextual data acquisition and processing.

S. Park et al. (Park, Hussein, & Crespi, 2015) presented a "socialization agent to support the evolution toward the SIoT that could be embedded into some of IoT devices by the policy and capacity of themselves" (p. 2). The authors propose an on-site available service discovery architecture which takes into consideration the practical IoT domains' formations and federations, by evolving from smart devices to social devices.

The authors of the (Lin, Ho, & Lin, 2014), define an NFC-based intelligent agent for the Social Internet of Things (presented in Figure 2) and propose a framework for developing this kind of agent, which combines the NFC technique with context-acquisition, ontology-knowledgebase, and semantic-adaptation modules, a credit-based incentive scheme to encourage social cooperation and to recommend relevant services. In order to enable the accommodation to the uncertain real-world environments, "this study also defines intelligent and social functionalities for the proposed NIA to achieve three indispensable abilities: reactive actions, proactive

Figure 2. Architecture of the NFC-based intelligent agent

Source: Lin, Ho, & Lin, 2014.



achievements, and social cooperation. In order to support context-aware computing, this study develops several mechanisms to support the abilities of location, time, activity, and social awareness” (p. 15). The resulting social-advertising system shows that this framework can support context awareness in the SIoT environments and a wide range of different functionalities.

The Social Internet of Things represents the extension of Internet of Things, which has great potential for various applications. Although, it lacks intelligence and cannot comply with the increasing application performance requirements from different domains, agent technology seems to be a promising approach in the implementation of the Social Internet of Things.

The next section briefly summarizes a historical evolution of medicine models and potential implications of SIoT adoption in healthcare.

MEDICINE MODELS AND SIoT

Over the years various P_n medicine models (where n takes values from 0 to 6) have been considered. Their evolution, taking into consideration their main features, is briefly summarized in Table 1.

The P_0 medicine model, strongly centered on the physician, is seen as the dawn of medicine, according to (Bragazzi, 2013). Gradually, we evolved from P_0 medicine to P_3 medicine, a model defined as personalized, predictive, and preventive. But paradigm changes with an additional feature of the new medicine model: participa-

Table 1. The evolution of medicine models

Feature	P0 Medicine	P3 Medicine	P4 Medicine	P5 Medicine	P6 Medicine
Personalized	No	Yes	Yes	Yes	Yes
Predictive	No	Yes	Yes	Yes	Yes
Preventive	No	Yes	Yes	Yes	Yes
Participatory	No	No	Yes	Yes	Yes
Psycho-cognitive	No	No	No	Yes	Yes
Public	No	No	No	No	Yes

tory. The editors of Journal of Participatory Medicine, Jessie Gruman and Charles W. Smith, define participatory medicine as “a cooperative model of health care that encourages, supports and expects active involvement by all parties (clinicians, patients, caregivers, administrators, payers and communities) in the prevention, management and treatment of disease and disability and the promotion of health” (Gruman, & Smith, 2009, p. 1). In fact, several terms have been used for this new model, such as: personalized medicine, precision medicine and P4 medicine. We consider that the first two terms do not express the four features of this paradigm, and, therefore we opt for the term P4 medicine. In comparison to traditional medicine, the P4 approach was regarded visionary. However, according to (Gorini, & Pravettoni, 2011, p. 1), this approach “lacks a consideration of the psychological needs and values that make each individual unique”. Consequently, the authors suggest adding the ‘fifth P’ standing for the psycho-cognitive aspects. And n was incremented, transforming P4 medicine into ‘P5 medicine’. P6 medicine (i.e., personalized, predictive, preventive, participatory, psycho-cognitive, public) entails the addition of the public feature as a conceptual evolution of P5 medicine. In fact, P6 medicine was defined by G. Cumming and others as “P4 + Cⁿ Hippocratic revolution”, where, according to Cumming G. et al. (Cumming, Fowlie, & McKendrick, 2013), Cⁿ stands for “community, collaboration, self-caring, co-creation, co-production, and co-development using technologies delivered via the Internet”. In accordance with (Bragazzi, 2013), “patients do not limit themselves to browse health-related information on the Web, but they actively exploit all of the Web’s potential”, including the social networks. In fact, according to (Topol, 2012), “our go-to source for health and medical information is moving away from our doctor—it is increasingly by crowdsourcing and friend sourcing our entrusted social network.”

We propose to extend these models. In fact, adopting Social Internet of Thing in healthcare could favor the development of a new form of medicine that ensures the fulfillment of healthcare delivery criteria as presented in (Srini, 2011):

- Content;
- Context;
- Communication;
- Convenience;
- Customization.

These are briefly described as $P6 + C^5$.

In this context, the meaning of the word “community” considered in the definition of P6 medicine ($P4 + C^n$) must be understood not only in human terms, but as a community of things (living and non-living entities).

The use of this new medicine model, encouraged by the adoption of SIoT in healthcare is in compliance with the right principles of healthcare delivery, presented in (Srini, 2011):

- Right Care (right to access and right to waive);
- Right Time;
- Right Place;
- Right Delivery Model/Channel;
- Right Price;
- Right Personnel;
- Right Partnerships.

These are described as $P6 + C^5 \Rightarrow 7R$.

Next section evaluates the potential and implications of Social Internet of Things approach for people suffering from asthma.

SIoT-Based Benefits for People with Asthma

Further on, we focus on presenting a Social Internet of Things (SIoT) approach to solve some problems encountered by the many people suffering from asthma. In fact, those who suffer from this chronic disease (children and adults alike) are not the only ones affected. Family members and friends may also be dealing with the issues, because they have to adjust their lives according to the special requirements of the patient. The use of information technology holds promise for improving the patients' overall safety and for enhancing the quality of medical services.

In order to meet the needs of asthma patients and to prevent asthma attacks, we propose a smart living, cost-effective and real-time solution based on a Social Internet of Things approach. Acute, severe asthma exacerbations or attacks can be life-threatening and therefore must be prevented by the use of medications and by reducing exposure to the environmental factors known as triggers. But because these

triggers differ from case to case, a good asthma management implies identifying those specific to a certain patient in order to limit exposure or to avoid them completely. In this context, the Social Internet of Things can prove really useful for enabling the efficiency of various information related to medical problems. In fact, the SIoT approach can be perceived as a natural extension of the current implementations which must take into consideration important additional IoT based resources and capabilities.

Asthma attacks are the result of some cumulative factors, such as exposure to cold air, pollution, dust, pet dander, exhaustion or even secondhand smoke. More important than recognizing the early warning signs of an asthma attack, is the attempt to prevent it. Some important living or non-living things, located indoors or outdoors, are included in this architecture. Things linked to people are a special category to be considered. Different types of sensors, moving at the same time with the patient, could be used to monitor his health parameters. For example, breath rate sensors developed by PASCO (PASPORT Respiration. (n.d.)) measure the breathing rate based on the air pressure in a mask worn by the patient. Usually, this sensor is used indoors, but if it communicates with another thing, like a mobile phone or a tablet, it would be included in the considered SIoT architecture. The values of breath rate and breath rate average parameter can be sent to the living things of the architecture, e.g. personal general practitioners, specialists, emergency team members, care giver, or family members. Moreover, the patient can wear different types of biosensors or an intelligent T-shirt (Monitoring patients using intelligent t-shirts, 2011), that can measure his temperature or can generate an electrocardiogram. There are many choices available on the market for global positioning system (GPS) receivers that could provide the patient's position (latitude, longitude, and altitude). When the values of the measured parameter exceed the patient's personal presets limits, the data are communicated to other things (especially to the emergency staff, if necessary).

Home things could also bring benefits when the patient's status is monitored. For example, indoor sensors or companion robots can be sources of environment status parameters sent to other things connected in a social relationship to the SIoT. Also, home appliances can tell something about the patient's activities (for example, the moment when the patient uses the vacuum-cleaner implies dust).

The patient could receive alerts from other things connected to the SIoT, such as, air quality monitoring stations, wireless pollution sensors, weather stations or even traffic monitoring systems. Based on these alerts signals, the patient (if pedestrian) can avoid polluted areas in the city, and thus preventing the occurrence of an asthma attack.

If we consider outdoor asthma triggers, the IoT local weather report can enable patients with asthma to monitor the weather conditions and the air quality. Based

on their social relationships in SIoT, people with asthma could receive information regarding location-based real-time index levels for pollen, asthma sensitivity, as well as the local weather forecast. Extreme hot, cold, or even humid weather, or rapidly changing climate conditions (e.g., changes in temperature and humidity, barometric pressure or strong winds, etc.) may also be asthma triggers. Also, patients with asthma living in areas where forest fires are common during the summer must pay attention to the poor quality of air. Regular exercise is healthy for patients with asthma, but the air quality must be taken into consideration. Thus, based on the local weather report, patients can schedule their outdoor activities when the air quality is suitable for their health status, thus avoiding exposure to high levels of pollen or pollution. Moreover, this kind of report helps patients to decide whether to use the air conditioner in order to filter the air coming into their home.

Using their social relationships in SIoT, people suffering from asthma have access to exact and real-time information regarding potential symptom triggers in their close environment.

CONCLUSION AND FUTURE WORK

The latest in advanced treatments and information technology came with the promise of improved efficiency in healthcare.

In this chapter we have focused on the social-oriented approach that we believe to be the gap between current medicine models and practice. Starting from the idea that the evolution of the Internet of Things to Social Internet of Things supports this approach, the present chapter aims to examine the adoption of the Social Internet of Things in healthcare. We address a broad range of techniques, methods, models, functionalities, middleware solutions, systems and applications related to SIoT. Next, some consideration related to evolution of P's medicine models and potential implications of SIoT adoption in healthcare are presented.

Additionally, this chapter provides an overview of the impact of the SIoT in healthcare, and tackles with the inherent challenges of making the use of SIoT a reality in the field. The Social Internet of Things has great potential for healthcare organizations and society. The benefits can be enormous, both for people and for healthcare organizations, if the development of SIoT is properly managed.

As healthcare professionals cannot afford to take risks, significant research is needed to make SIoT at healthcare a reality. Thus, according to J. A. Stankovic (Stankovici, 2014, p. 6), “new research problems arise due to the large scale of devices, the connection of the physical and cyber worlds, the openness of the systems of systems, and continuing problems of privacy and security”. Besides the IoT

challenges, SIoT brings its own challenges in order to facilitate new applications and services in more effective and efficient ways. Some of these challenges are the following:

- Ownership;
- Defining/enabling relationship between things;
- The heterogeneous nature of the connected devices (resolving this problem will increase inter-things communications in the SIoT);
- Concurrent access to connected devices; aiming to limit costs, medical units must determine the optimal number of devices that provide the same service. On the other hand, in SIoT, multiple users can simultaneously try to access the same equipment, which can lead to blockages in the system. Establishing a system of priorities in accessing connected devices or temporally limiting the access to them, may be part of the solution to this problem;
- Conflicts between devices;
- Function redundancy;
- The establishing of a level of trustworthiness between connected devices that are “friends” (Chen, Bao, & Guo, 2014; Nitti, 2014; Nitti, 2015);
- Non-standardization.

Despite the many problems faced by the adoption of SIoT in healthcare, this paradigm promises to deliver to human users and connected devices the possibility to discover, select, and use proper services found through scanning their friends network.

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