SPWID 2015

The First International Conference on Smart Portable, Wearable, Implantable and Disability-oriented Devices and Systems

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SPWID 2015

Foreword

The First International Conference on Smart Portable, Wearable, Implantable and Disability-oriented Devices and Systems (SPWID 2015), held between June 21-26, 2015, in Brussels, Belgium, is an inaugural event bridging the concepts and the communities dealing with specialized implantable, wearable, near-body or mobile devices, including artificial organs, body-driven technologies, and assistive services

Mobile communications played by the proliferation of smartphones and practical aspects of designing such systems and developing specific applications raise particular challenges for a successful acceptance and deployment.

We take here the opportunity to warmly thank all the members of the SPWID 2015 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to SPWID 2015. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the SPWID 2015 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that SPWID 2015 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the areas of smart portable devices and systems.

We are convinced that the participants found the event useful and communications very open. We hope that Brussels, Belgium, provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of the city.

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Design Direction Analysis for a Health Knowledge Transfer System for Deaf People and Health Professionals in Cape Town

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***Abstract*— Many South African Deaf people use South African Sign Language (SASL) for communication, but are less skilled at reading and writing. In the context of healthcare, adult Deaf patients and health professionals therefore face problems with communication. These communication barriers hinder many Deaf people from accessing health information from various sources. Deaf patients need to understand conversations at a health facility, and also to receive accurate and comprehensible health information that supports their understanding of the diagnosed disease for self-management. Health Knowledge Transfer System (HKTS) is a proposed branch from a research and development project on a mobile communication tool (SignSupport) for a Deaf person in healthcare contexts. This paper describes the findings retrieved during the exploration phase regarding the design direction of the HKTS using a community-based co-design (CBCD) approach. Deaf adults and health professionals from Cape Town participated in this research. Health information about Type 2 diabetes as a case study and mobile devices as information transferring tools were selected. The HTKS is envisioned as part of an assistive device for health care system integration to provide information in SASL thus serving the needs of the Deaf patients. It focuses on a scenario in which the targeted diabetic Deaf patients can access health information from anywhere.**

Keywords-Deaf patients; low health literacy; community-based co-design; health information sources; mHealth.

I. INTRODUCTION

Deaf with a capital 'D' refers to a cultural group of people with hearing loss who mainly use a signed language for communication; many of them have limited reading and writing skills [1]. In the South African healthcare context, Deaf patients and health professionals have problems with communication, in the absence of a SASL interpreter, due to their language differences [2]. Therefore, our research team, together with a Deaf NGO, started developing a communication tool on Android mobile phones called "SignSupport" to bridge limited and patterned conversations through the CBCD approach [3]. The communication during a medication dispensing process was taken as a specific case study. SignSupport prompts a pharmacist to explain the medication instructions by typing in and selecting buttons matched with pre-recorded SASL videos, so the Deaf patient can view and understand the instructions [4][5]. The research team later found that Deaf patients needed to acquire additional health information to support their understanding of the diagnosed disease and self-management. Consequently, we decided to branch out with a sub-project to design and develop a HKTS which addresses this need amongst Deaf patients and health professionals. The system aims to provide adult Deaf users with comprehensive information in signed language and in their preferred presentation method on a low cost mobile platform.

Section 2 of this paper presents the background information from literature reviews. Section 3 accounts the methodology used in the project. Section 4 describes the empirical findings covering the current situation of health information distribution from the point of view of both Deaf people and health knowledge providers, including the ideas for solutions from all participants. Section 5 explains the decisions made on the design direction. Section 6 envisions the integration of HKTS and SignSupport, and the co-design of the information content and its presentation techniques as future work. Section 7 concludes with the work that will be proceeded after this exploration.

II. PROJECT BACKGROUND

Many South African Deaf people experience a disparity in accessing comprehensive health information.

A. Problems in health communication

Health professionals and Deaf patients in South Africa frequently experience communication problems in the absence of the scarce, and relatively expensive, SASL interpreters. The most common problems are as follows:

1) Language differences: A signed language cannot be translated word-for-word to a spoken or a written language, or vice versa, due to the differences in sentence structure [6]. This is why the majority of Deaf people find it difficult to learn and understand a spoken or a written language [7]. The majority of South African Deaf adults can therefore read and write only simple vocabulary, are unable to communicate with health professionals, and have limited exposure to health information from the mass media. Problems in health communication can have an adverse effect on the patient's health condition [8][9].

2) The lack of SASL interpreters: The communication problem could be overcome with the assistance of signed language interpreters. However, only 84 SASL interpreters are registered at the National Institute for the Deaf [10]; this number of registered SASL interpreters is inadequate to serve the demands of approximately 600,000 South African Deaf people across the country [11]. In addition, 90% of the Deaf population is born into hearing families many of whom cannot sign [12]. These reasons explain why many Deaf patients cannot easily find a SASL interpreter or a family member who is capable of communicating in SASL to escort them to a health facility [2].

B. Interferences with information understanding and adherence

Misconceptions and the lack of fundamental knowledge can interfere with the understanding of the given health information and the subsequent adherence to the suggested treatment from a health professional [13].

1) Health misconceptions: Several misconceptions about various diseases, their prevention and detection, and treatment were found by different researchers. Deaf people in a community share similar health misconceptions through close-knit communication, e.g., the so-called “grapevine”; and it is difficult for a hearing health professional, who is an outsider, to influence them [4][14]-[16]. Many Deaf individuals do not question new information they receive from others, unless it goes against their own beliefs [2].

2) The lack of fundamental health knowledge: This is caused by a number of issues which are that (1) Deaf people receive inadequate health education during childhood [4], (2) many Deaf individuals miss opportunities to receive health information through incidental learning, especially from their hearing family members [17]. Lastly, (3) due to functional illiteracy, the vast majority of Deaf people have limited exposure to health information promoted via the mass media [18]. Without fundamental knowledge, Deaf people can hardly detect erroneous health information shared among their Deaf peers nor understand the health explanations from health professionals.

III. METHODOLOGY

A. CBCD approach

In the field of Information and Communication Technologies for Development (ICTD), the CBCD approach is applied by research groups in different countries to deal with multiple stakeholders and social complexity [19]. Our research team applies CBCD as part of action research, which involves end-users and communities with their social and cultural factors in design stages. We explore and develop solutions with participants in order to achieve an accessible and viable HKTS in the Cape Town context [3]. The decisions for the design direction of the HKTS were made based on the preferences, ideas and preliminary requirements from Deaf and health knowledge provider participants. There were four main considerations within this decision making process, which were: (1) the type of media to provide Deaf people access to health information (i.e., TV or mobile phone), (2) health information of interest and relevance for Deaf participants (i.e., type of disease), (3) the targeted group(s) of Deaf users of the HKTS, and (4) the targeted group(s) of health knowledge provider users of the HKTS. The research team then planned to start the design and development process with a relevant case study.

B. Methods

Interviews with sensitizing tools were applied to the research with Deaf participants and health knowledge provider participants. All the Deaf participants were interviewed in groups, while the health knowledge providers were interviewed either in groups or individually based on their availability. The interviews aimed to (1) identify the organizations and individuals who are the current health information sources to Deaf people in Cape Town, (2) investigate problems in the transfer of health information between the information sources and Deaf people, (3) define both effective and ineffectual techniques in health information transfer, (4) identify urgently needed health information among Deaf people, and (5) elicit ideas for solutions for improved health information transfer.

The interviews were conducted with different groups of Deaf people: males, females, and Deaf families. These interviews covered topics (1) to (5). Next, we approached health professionals who were frequently mentioned as health information sources by the Deaf participants. The interviews with these health professionals touched upon topics (2), (3), and (5). The health professional participants were health policy makers, Deaf health workers (health workers who are Deaf themselves), and hearing healthcare providers. These participants have experience in providing health information and services to Deaf people. A qualified SASL interpreter assisted in all interviews with the Deaf participants.

C. Techniques used for data collection

1) Question sets for the interviews: There are two different sets of questions— one for Deaf people and one for health professionals. The questions facilitate them to think about their experiences during health communication and solutions that could meet their needs.

2) Sensitizing tools for Deaf people’s reflection on their access to health information from different sources: The researcher wrote down on sticky notes each health information source mentioned by the Deaf participants during a group session. After leading the participants through the questions, they were asked to discuss within their group, and rate their accessibility to, each mentioned source on a ‘map’ of A0-sized paper. The map was divided into five areas, using scales of zero to five, from very poor to high accessibility, respectively. Thereafter, the participants were asked if they wanted to adjust their rating or to add any missing health information sources.

3) Sensitizing tools for eliciting ideas for solutions from Deaf people and health professionals: After sharing their experiences and the communication techniques used during health communication, the participants were asked to think of solutions that could meet their needs in effective health information transfer. Sheets of A4-sized paper, coloured markers, stickers in different shapes and colors were provided to participants to express their ideas.

D. Participants

Participants were invited from different Deaf communities and health organizations in Cape Town.

1) Deaf people: (1) Male group and female group— Six Deaf males and six Deaf females were invited from two Deaf communities. Their level of hearing loss, education, health literacy, and experience with telecommunication and technology were disregarded. (2) Deaf family groups— Three Deaf families (altogether eleven participants) who have low-to-medium experience with technology and the internet, were invited from two Deaf communities to join separate group interviews. Each group consisted of a Deaf father, a Deaf mother, and at least one child who was attending school regardless of the child's hearing ability.

2) Health professionals: (1) Health policy makers— Two participants from a governmental organization were approached for a group interview. (2) Deaf health workers— Four health worker participants who are Deaf from a Deaf community were invited. These participants were trained specifically for HIV/ AIDS counselling. (3) Hearing healthcare providers— Two doctors, one nurse, and one clerk were approached from a public health community centre where several Deaf people visit.

E. Ethics

All participants were informed about the objectives of the interview, the activities, and also their participation rights. The participants were asked to give consent to the research team before the interview started. All interviews were video recorded and were to be kept in secured storage with access by the research team members only.

IV. RESULTS

The outcomes that are of relevance for the upcoming CBCD process can be described as follows:

A. Overview of health information distribution modes to Deaf people

The Department of Health of the Republic of South Africa promotes the distribution of information about diseases by partnering with Deaf organizations. The Deaf organisations invite Deaf members to distribute the information through health events. There are only four Deaf health workers in Cape Town, and all are based at one Deaf NGO. These Deaf health workers organize health events and individual counselling in SASL through available subsidy. In addition, Deaf people can also acquire health information during consultations with doctors.

B. Problems in health information transfer

Health policy makers were aware of the problems in distributing information and services to the Deaf population. They also realized the critical lack of SASL interpreters in the health care context.

Several of the hearing health professionals tended to write to communicate with the Deaf patient during the communication in the absence of a SASL interpreter, without knowing that the patient could not fully understand the written messages nor easily find someone at home to interpret for them. Some auxiliary information, which could help the patient build up their understanding and knowledge about the disease, was discarded due to communication breakdowns. In addition, some health professionals also required lip reading skills from Deaf patients during the explanation about health information.

Deaf health workers are eligible persons who are Deaf or have SASL competence. They are trained for specific counselling, viz. HIV/AIDS. These workers may not have knowledge about other diseases beyond their trained subject. However, Deaf clients normally approach them with questions about all types of diseases.

Health information available in the mass media is not fully understood by a Deaf audience due to their functional illiteracy and hearing loss.

C. Existing vs. ideal health information sources

Deaf people mentioned a range of existing sources for their acquired health information. The two most frequently mentioned sources are consultation with a doctor in the absence of a SASL interpreter, and health workshops and counselling provided by Deaf health workers from a Deaf NGO in Cape Town. Several other health information sources such as the mass media (e.g., newspapers, TV programmes, and health pamphlets) and individual persons (e.g., friends and parents) were considered as existing health information sources with less frequent mention. Figure 1 presents the ranking of existing against ideal health information sources.

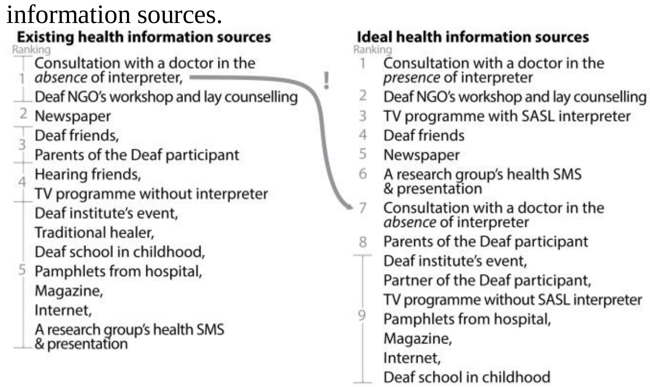

Figure 1. Existing *vs*. ideal health information sources.

Consultation with a doctor in the absence of a SASL interpreter was noted as a frequent health information source. However, the information provided by doctors (or other health staff) was not understood by the Deaf patients. As a result, the ranking of this source as an ideal health information source to Deaf people is relatively low. Health workshops and counselling provided by Deaf health workers from a Deaf NGO was highly rated as an existing source that Deaf people turn to, and also as an ideal information source. Deaf participants expressed their satisfaction with health drama in SASL performed by the Deaf health workers, who also provided a Q&A platform to the Deaf audience.

D. Health information of interest to Deaf people

Deaf males, Deaf females, and Deaf families were asked to discuss and prioritize the top three health information topics which are the most relevant for their own group. The Deaf health workers were also asked to prioritize the health information which is urgently needed by all Deaf people. The results are described in Table I.

TABLE I. THE PRIORITIZED HEALTH INFORMATION OF INTEREST AND RELEVANCE FOR SPECIFIC GROUPS OF DEAF PEOPLE

For the interest and relevance of	**Information of interest in prioritized order**		
	1st	***2nd***	***3rd***
Young Deaf men	safe sex	sterile circumcision	sexually transmitted diseases
Deaf women	cancer	depression	swollen feet
Deaf parents	diabetes	cancer	children's health
All Deaf people	diabetes	hypertension	tuberculosis

As a result, diabetes was concluded as the most popular and relevant health information of interest among the Deaf paticipants.

E. Effective and ineffectual techniques in delivering health information to Deaf people

These findings were extracted from the responses of all participants.

1) Effective techniques: (1) SASL is the "mother tongue" among South African Deaf people. Therefore, delivering health information in SASL is the most effective technique. (2) Drama in SASL is a form of health information delivery that Deaf people appreciate. The health drama delivers information inclusive of entertainment. It also covers information to correct health misconceptions among Deaf people. (3) Pictures with concise text descriptions. Some Deaf participants mentioned optimizing their understanding of concepts with pictures combined with short descriptions.

2) Ineffectual techniques: (1) Communication that requires reading and writing skills from Deaf people is not effective because many Deaf people are functionally illiterate. (2) Communication that requires lip-reading skills is also ineffectual. The accuracy of English messages understood via lip-reading is only about 30-35% [20].

F. Ideas for solutions from all participants

We retrieved 45 ideas from drawings and verbal/signed explanations by participants. These ideas were sorted into three categories, which are solutions through the use of (1) human-to-human interactions (16 ideas), (2) mass media (12 ideas), and (3) ICT (information and communication technology) (17 ideas). The most popular ideas from each category respectively are an increase of the health drama teams by involving more Deaf members (C 1), TV programmes, health videos at health facilities, and health DVDs with SASL interpretation (C 2), and mobile devices as a health knowledge tool (C 3). Table II shows the analysis of the suitability of each popular idea as a solution in the Cape Town context.

TABLE II. ANALYSIS OF SUITABLE SOLUTIONS FOR IMPROVING THE HEALTH INFORMATION DISTRIBUTION IN THE DEAF CONTEXT

Considered performance	**Popular solutions proposed by participants**		
	(C 1)	***(C 2)***	***(C 3)***
Accommodate different data types of information (SASL videos, pictures, texts)	√	√	√
Available health communication bridging	×	×	√
Allow information reviews, private search, self- learning	×	× (TV programmes & health videos at health facilities) √ (health DVD)	√
Can be updated by health knowledge providers	√	√ (health videos in the waiting areas of health facilities & health DVDs) × (TV programmes)	√
Initial cost of production and development	Medium	Medium	Medium
Operational cost	Medium	Low (health videos at health facilities & health DVDs) High (TV broadcasting)	Medium

Costs were estimated from the monthly allowance for a research assistant to develop and maintain the system and an allowance for groups of four Deaf people to prepare a drama.

V. DISCUSSION

This section discusses the decision-making on the design direction of the HKTS design and development.

A. Decision-making on the design direction

1) Type of solution to improve access to health information: The type of solution was selected based on the considerations as stated in Table II. Mobile devices have the potential to present information in SASL videos, as Deaf people explicitly expressed this need, and in mixed media.

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2) Information for the disease of interest among Deaf people: Type 2 diabetes is selected for this case study due to the interest of Deaf participants and also its prevalence in the health care context of South Africa. There are 3,500,000 people in South Africa (6% of the population) suffering from Type 2 diabetes [21]. We can assume 1%, i.e. 35,000, are Deaf (similar to the 1% of the population being Deaf as opposed to deaf and/or hard-of-hearing).

3) Targeted groups of Deaf users: Middle-aged males and females and mothering females are the targeted groups of Deaf people for this case study. These people are in the age range of diabetes onset, and they are amenable to the use of mobile devices as the tool for accessing information.

4) Targeted groups of health knowledge providers: Doctors and ancillary staff who are involved in diabetes care will be invited to join this participatory research. They will be asked to provide insights into what diabetic patients should know, understand, practice, and manage.

B. Preferred information transfer methods to Deaf users

Deaf participants required viewing health information in SASL. They also favour health dramas in SASL as they have experienced from a Deaf NGO in Cape Town. However, the entertaining elements in the drama may deflect the audience's attention from the important health messages. In addition, coherent pictures can enhance the understanding of the information among Deaf users because of their strong visual-spatial working memory [22].

VI. FUTURE WORK

The designed and developed HKTS is meant to complement the use of SignSupport (see Figure 2) as it will be a relevant health education source for Deaf adults.

A. Integration of HKTS and SignSupport

Deaf patients can use SignSupport (Communication tool) to communicate with hearing staff at a public health facility, from arrival until departure. Figure 2 indicates the stages at which a doctor or ancillary staff members can refer to different topics of health information from the HKTS (health knowledge source) to explain the diagnosed condition and self-management. This will help the patient understand the disease in more depth and can help improve or maintain their health condition at home.

B. Co-design of information content and the transfer process with end users

Co-design with Deaf participants with Type 2 diabetes and diabetes doctors and involved ancillary staff will take place in Phase 2 of the research to define the design of the health information content and the delivery structure in detail. Together with these participants, the research team can (1) identify the information (based on or in addition to the topics proposed in Figure 2) which need to be available on the HKTS, and (2) understand suitable methods to transfer health information that meets Deaf people's requirements and their learning capabilities. We envisage that the end-users will require a mix of techniques in delivering specific health information, e.g., Deaf patients may require explanation about insulin through the combined techniques of animation and SASL narration. This assumption will be explored and validated during the co-design sessions.

VII. CONCLUSION

This HKTS can be one of the ways to solve the challenges of Deaf people's inaccessibility to health information due to language barriers and the scarcity of a signed language (SASL) interpreting service for healthcare. It will complement the use of the mobile communication tool, SignSupport, to provide access to accurate and comprehensible health information for Deaf people. The design direction of the HKTS is selected. Its content and structure will suit the SASL communication needs of Deaf people. The content and the structure will be designed through a case study of Type 2 diabetes care in the Cape Town context. Deaf users in the middle-aged and mothering phase are at risk of this type of diabetes, so they, and the health professionals (doctors, clinical nurses, and ancillary staff) involved, are invited to join the design case study of the HKTS. These users can have access to the information about fundamental knowledge of the disease, self-management, and life-style modification. The main approach is CBCD, or so called─ a participatory design approach. Therefore, Deaf and health professionals will collaborate with the research team to derive an accessible and viable HKTS. We expect that the derived content structure will be applicable to the information for other chronic diseases.

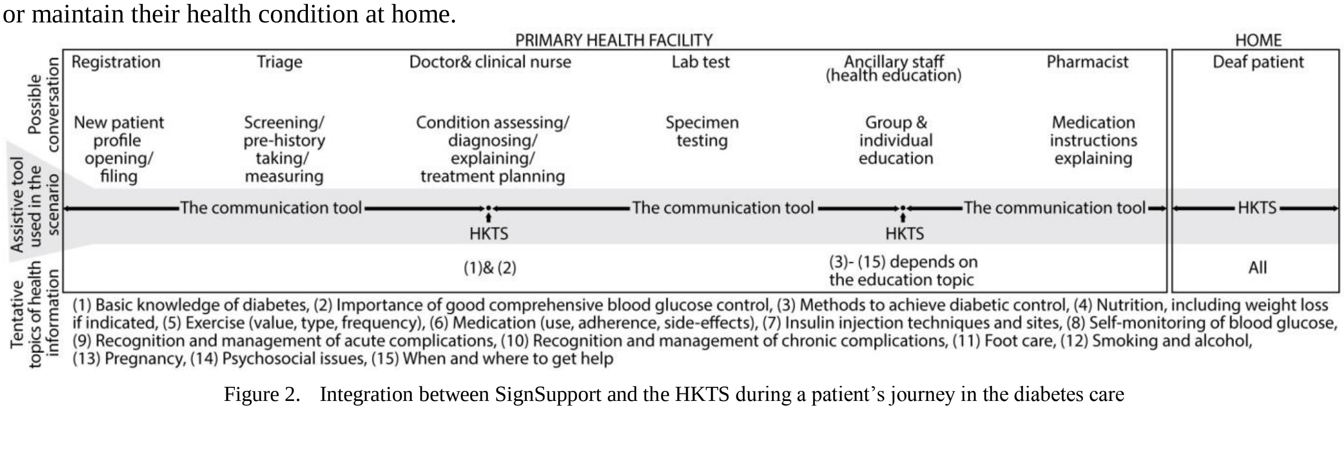

Figure 2. Integration between SignSupport and the HKTS during a patient's journey in the diabetes care

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Towards a Multi-agent based demand-driven control of Building Systems.

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Abstract— **Occupant presence and behavior in buildings have been shown to have a significant impact on the energy consumed in buildings for space conditioning. Towards effort to improve the energy efficiency and performance of buildings, demand driven control of building systems and appliances have been proposed and implemented in a number of studies. A core component of demand-driven control in building operation is occupancy detection. The performance of the occupancy detection system impacts the controllability of demand driven applications, the accruable energy savings and comfort of building users. This paper provides initial results from an ongoing research into the development of a multi-agent system (MAS) coordinated demand–driven control application for building operations which utilizes a robust and low-energy wireless sensor network (WSN) technology for occupancy measurement.**

Keywords—Multi-agents; Wireless sensor networks; Energy; HVAC systems

I. INTRODUCTION

It is a well-established fact that the primary role of buildings and building services is the provision of a comfortable, healthy and safe work as well as living space for its inhabitants [1]. In performing its functions, buildings have been shown to account for between 30-35% of total final energy consumption in the USA, EU and other Organization for Economic Cooperation and Development (OCED) countries [2-4]. The impact of building energy consumption on the sustainability of non-renewable energy supply sources and greenhouse a gas emissions has resulted in it being the target of a number of energy efficiency improvement strategies [5]. To this end, buildings have been identified as a key potential contributor to efforts to safeguard security and sustainability of energy supplies as well as efforts to mitigate climate change [6].

In buildings, lighting, heating, ventilation and air–conditioning systems are the top energy consuming systems, both accounting for more than half of total energy consumed [7-8]. Several studies have shown that the interaction of building occupants with these building systems and their controls has a greater impact on energy consumption [9]. It has therefore become more important to understand individual behavior of building occupants as well as fine-grained evaluation of energy end point utilization in buildings in order to help reduce energy consumption and carbon emissions in existing buildings.

Demand-driven control strategies are measures aimed at improving the energy efficiency and performance of building systems through the use of actual building occupancy information. This includes measures such as turning off or dimming artificial lighting systems and controlling the ventilation, heating and cooling of spaces using actual occupancy information. As demonstrated in a number of studies [10], energy savings of between 3-84% can be achieved in office buildings through demand driven control of lighting systems. Also as demonstrated by the authors in [11] through dynamic occupant driven use and control of HVAC systems in an office, energy savings of up to 30% was shown to be attainable. A core component of demand-driven control applications in building operation is occupancy information. Information on occupancy, may lead to very fine delivery of lighting and heating, ventilation and air conditioning and visualization of the use of space.

Over the years, a number of studies [12] have developed occupancy prediction models for control processes in building operation. Though with impressive results, these models are often building specific and do not proffer a generic solution to occupancy measurement in buildings, which varies with a building’s functions, location and person. As a result, most commercial buildings still operate based on fixed schedules and assumed occupancy information, despite studies showing

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that average occupancy in buildings even at peak times is usually below 70% [13-14].

Of recent however, non-model based generic solutions providing near real-time occupancy information and based on wireless sensor network technologies [15-16] are been considered in demand-driven control applications in buildings.

In addition, for coordination of demand-driven control applications, solutions based on the multi-agents design paradigm are also been introduced in building operation as a result of their distributed, autonomous and adaptive capabilities [13, 17].

The subsequent sections of this paper describe the design framework for a MAS coordinated demand driven control of building systems and appliances utilizing wireless sensor networks for occupancy detection. The proposed system can be integrated into existing building's comfort and energy management system for control of lighting & HVAC systems to improve buildings responsiveness to demand response and smart grid interaction. Initial experimental results from the test-bed building are also presented as well as the energy savings obtainable from the application of the proposed system in operation of the building.

II. BACKGROUNG

A. *Sensor network and localization*

The advancement in radio and embedded systems technology has significantly enhanced the proliferation of various wireless communication systems in a large number of end-use applications. A representative of this class that has received considerable attention from the research community is wireless sensor network, which consist of numerous tetherless devices that are released into the environment and organize themselves in an adhoc fashion [18, 19]. The main goal of wireless sensor networks in most application is to perform monitoring tasks and a key component of tasks monitoring applications is information on the location of occurrences/events. Not only is this information needed for the sensor network to report the location where events take place, it also assists in group-querying or routing traffic to a designated geographic destination and provides information on physical network coverage [18].

In general they are composed of three major components as depicted in figure 1[15, 18]; (a). A transmitting device- with the capability to communicate with other nodes within a certain communication range using signals such as radio frequency (RF), acoustic, infrared and ultrasound [19,20]. The nodes can either be an active or passive and includes devices such as RFID (radio frequency identification) tags, mobile phones, laptop computers enabled with a transmitter; (b). A receiving device or readers; (c). A data collection and processing sub system.

In applications requiring localization, the system measures either the timing or energy of the transmitted signal and uses the information to estimate the location of mobile nodes. A detailed discussion of these methods can be found in [19]. In wireless sensor network applications based on RF signals, the received signal strength indicator (RSSI) which is used for network planning and localization [18]. Measurement of the RSSI from nodes is a distance estimation technique that uses the measured signal power at the receiver and the known transmit power to estimate propagation loss. The propagation lose is subsequently translated into distance using theoretical models.

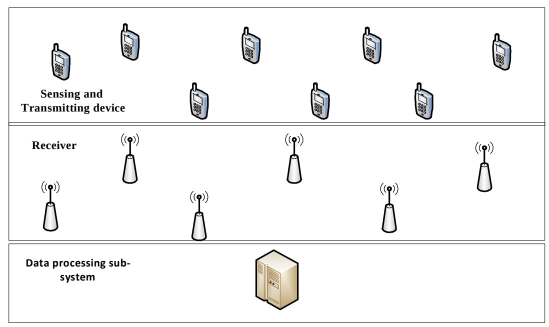

Figure 1: Client/server Wireless network components

B. *WSN in Demand driven applications in buildings*

For demand driven control applications in buildings, the common desires information on building occupancy as shown in figure 2 includes [16, 21];

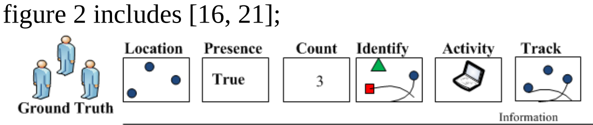

Figure 1: Occupancy Information

(A).Location- which provides information about 'where' in the building or particular thermal zone within the building occupants are situated (B).Presence- provides information about 'when' particular occupants are in particular thermal zones within a building; (C).Count- provides information on the 'number' of occupants in a particular thermal zone; (D).Identity-provides information on 'who' is in particular thermal zones; (E). Activity- provides information on 'what' activity is been carried out by individual occupants in particular thermal zones. (User activity determines the body metabolism rate which is one of the parameters required in the determination of thermal comfort [22]); (F) Track- provides information about particular occupants movement across different thermal zones in the building.

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In a comparative study, the authors in [20] investigated the performance of different wireless systems utilizing the RSSI distance estimation method in indoor localization applications. Also using RFID tags, the authors in [15] demonstrated the capability a system utilizing the RSSI distance estimation technique to provide information on location, presence, count, activity, identity and track. In both studies and other similar studies on the use of WSN in building operations for localization [23-25], the network design were mostly centralized and based on the client/server communication architecture depicted in figure 1. In client/server network architecture, static nodes with known locations transmit messages such as; the received signal strength indicator, contact time, and nearest neighbor information to a processing station wherein, the position estimation algorithm is installed.

In occupancy measurement for demand driven control applications in buildings, the centralized nature of the client/server localization architecture does however pose a number of challenges:

(a) **Delayed control response time**- Users might have to tolerate some level of discomfort as a result of the delay from aggregated communication between the sensing, control and actuation nodes [26].

(b) **Complex and high computing requirement-** In studies that have demonstrated the feasibility of wireless sensor based localization [15, 20] indoors, a limited number of participants were considered and complex computing was required to obtain the needed information. In a typical commercial office building, occupancy count is usually much higher than demonstrated in these studies, thus becoming more complex and requiring more processing power.

C. *Multi-agent systems(MAS) for demand driven control applications.*

Considering the drawbacks of the client/server WSN architecture in demand-driven control applications in buildings, solutions based on the MAS paradigm have been proposed [13, 26]. In artificial intelligence, agents are physical or virtual entities that intelligently interact in an environment by both perceiving and affecting it [13]. Consequently an agent can be described as a computational system with a high degree of autonomy performing actions based on the information received from the environment. A system comprising multiple intelligent agents, commonly referred to as a multi-agent system (MAS). Within a MAS, agents interact to achieve cooperative (e.g. distributed problem-solving) or competitive (e.g. coalition formation, auction) group behavior. Agents achieve this by sharing a minimum amount of information between modules and asynchronous operation implemented via message exchanges [27].

The concept of intelligent agent technology is at an intriguing stage in its development as commercial strength agent applications are increasingly being developed in domains as diverse as manufacturing, Unmanned Aerial Vehicle (UAV) mission management and in operation and management of the smart grid [27-28]. In wireless sensor network applications, they are capable of roaming in the network, collecting data, aggregating and making decisions at the node level [29]. The agent paradigm promotes the use of independent, loosely coupled software entities that encapsulate some specific functionality and interaction with each other to solve tasks. The authors in [27-31] summarize the key features of MAS as:

- **Autonomous nature**- agents can act rationally and operate without the direct intervention of humans. They have individual internal states and goals, and act in such a manner as to meet their goals. A key element of autonomy is pro-activeness, i.e., the ability to ‘take the initiative’ rather than acting simply in response to their environment.
- **Co-operation**- agents may interact with each other both indirectly (by acting on the environment) or directly (via communication and negotiation). To co-operate, agents need to possess a social ability, i.e., the ability to interact with other agents and possibly humans via some communication language.
- **Intrinsic distributed nature**- A MAS system is a distributed system consisting of multiple agents, which forms a loosely coupled network, in which agents work together to solve problems that are beyond their individual capabilities or knowledge of each individual agent. In addition, they are mobile, scalable and modular, able to transport from one machine to another
- **Learning ability** - agents are able to learn and adapt to changes in the environment they live in. A key attribute of any intelligent being is its ability to learn and for agent systems to be truly intelligent, they would have to learn as they interact with their environment. In addition, agents are reactive which makes them respond to changes in the environment in a learned way and timely fashion. Agents are also goal oriented, acting in own self-interest and do not just act in response to the environment.

III. PROPOSED SYSTEM ARCHTECTURE .

A. *General System Architecture*

Leveraging on the above described capabilities of MAS, we propose a system with the architecture depicted in figure 2 and comprised of the following agents- manager, room, zone, building, and occupancy and user agents.

Manager agent- MAS design paradigms provides a flexible framework in which agents can be included and remove at any time without causing disruption in the systems operation. It is however necessary to have up-to-date information about the state of agents operating in the system. The task of the Manager agent is thus to monitor all agents (active, passive, dead or alive) operating in the system.

Room-agent- The room-level is critical for striking a balance between user comfort and energy efficiency as this is where both goals have contradictory requirements. The role of the room agent is hence a decision maker. Using information on the room properties, actuation and control possibilities, room state, occupancy information as well as user preference, the room agent determines the optimal room condition to satisfy the building policy on energy and comfort.

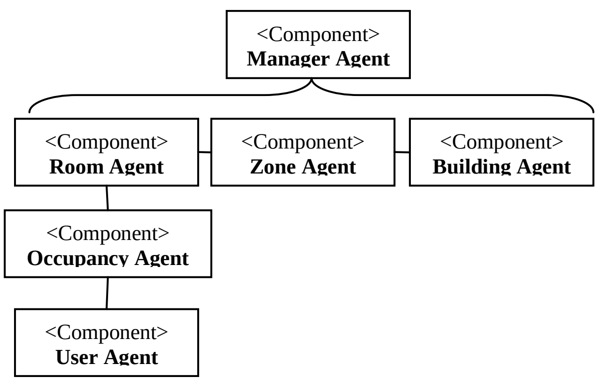

Figure 2: Architecture of the proposed MAS Demand control system

Zone-agent- In the design of building thermal systems, it is common to have areas of a building having similar cooling/heating requirement to be either virtually or physically grouped. A zone can thus be a group of rooms, a single room or multiple floors, which share comfort resources such as ventilation, heating and cooling. Depending on the building layout and design, the zone agent is responsible for optimal delivery of required comfort index of occupants located within particular zones in an energy efficient manner. In cases where the distribution of resource is shared with multiple rooms, the room agent would have to communicate with the room agent on the most efficient means of resource sharing.

Building agent- The building agent performs the role of an aggregator. It collates and aggregates information on energy utilization within the building. With more fine-grained information on energy utilization in the building, the buildings responsiveness to demand response and smart grid interactions can be improved [32].

Occupancy Agent- The occupancy agent provides the room agent with more fine-grained occupancy information. Further detail on the occupancy agent is provided in subsequent sections.

User Agent- The user in conjunction with the occupancy agent provides information on user identity, preference and activity to the room agent.

B. Physical Architecture.

The physical architecture for the proposed MAS system for an Integrated Room Automation (IRA) for office buildings is depicted in figure 3. IRA deals with the automated control of blinds, electric lighting, heating, cooling, and ventilation of an individual building zone or room. As shown, the setup is comprised of three agents- the user, room-occupancy, and room agents.

Users-agent- The user agent are mobile devices such as RFID tags, mobile phones or devices with radio signal transmission capability. Each building user is provided with a device which is unique to individual building occupants. This agent provides the room-occupancy agent with user identity information (tag ID), activity (analysis of the RSSI) and presence.

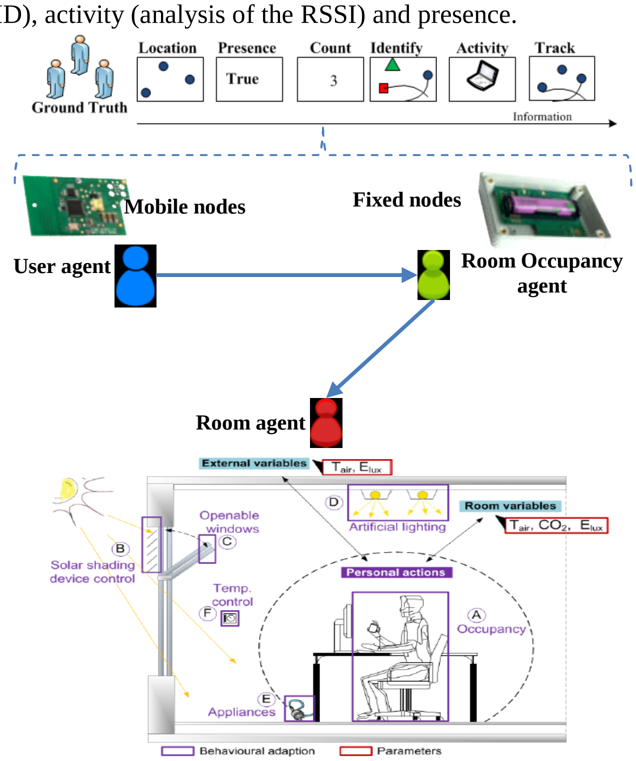

Figure 3: Physical architecture of the proposed System.

Room-occupancy agent- These are fixed nodes with assigned to particular building rooms and other known locations such as exits, conference rooms and lunch rooms. The room-occupancy agent obtains the RSSI from mobile nodes as well as the ID. It analyses the RSSI signal and provides information about user presence, count and activity which is sent to the room agent. For tracking, room occupancy agents at known locations exchange information with room occupancy agents assigned to particular rooms. As an example, through measurement of the RSSI, the room occupancy agent assigned to room A of an office building is able to determine if the particular room occupant through the tag ID has exited the room to the conference room. It however awaits information from the room occupancy agent in the conference room before passing the information to the room agent.

The room–agent- The room agent receives occupancy information from the room occupancy agent assigned to individual rooms and adjusts the room conditions based on the received information. As an example, since each building occupant is attached to known offices and do have a unique ID. When the room agent receives information about the presence and departure of unassigned user ID's in the room it is assigned, it sends the needed control signal to the room actuator so as to conserve energy and improve user comfort.

In addition, considering the slow response of some building systems such as HVAC systems, the room agent uses the track information provided by the room-occupancy agent to make time-dependent adjustment to building systems in a manner that does not disrupt the comfort of building occupants.

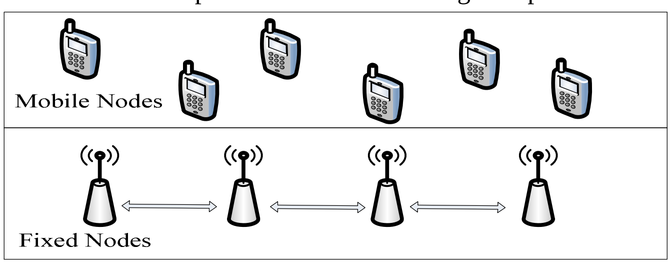

Figure 4: Agent based detection system

In contrast to the typical client/server wireless network model, the required information such as user location, presence and identity is shared between nodes. As information exchange is between nodes and decision making is decentralized, network resource is more adequately utilized thus reducing congestion while also making the systems more robust.

IV. EXPERIMENTAL SET-UP

A. The wireless network

In order to test the performance of the wireless sensor network indoors as well as to provide data for performance comparison, a WSN for occupancy detection was implemented in a test-bed office building. Utilizing a low-cost, low power WSN system based on the MyriaModem and MyriaNed [33]. For communication between nodes, the network does not utilize any particular topology but utilizes a gossip mechanism. To accomplish synchronization between wireless nodes without the risk of a separate network evolving, a join mechanism is embedded in the nodes. Through this mechanism all nodes are synchronized.

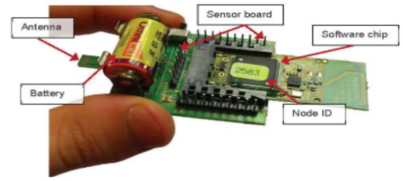

Figure 5: Mobile and static nodes

B. Test-bed office building.

The initial test setup was implemented on the whole floor of an office building with area of approximately 500 m^2. The floor is made up of 29 flexible open plan work spaces and 5 cell offices. For the purpose of this experiment, 18 employees with workspaces located in the flexible open plan spaces participated fully for a period of three weeks.

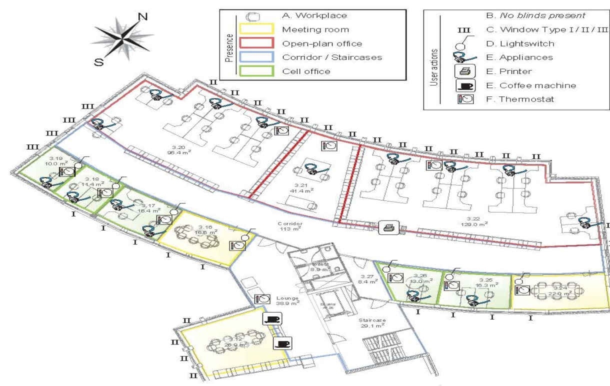

Figure 6: Test-bed office building

Each participant was assigned a node depicted in figure 4. The static and mobile nodes are physically the same but run different application software.

C. Experimental Results

Using the described client/server WSN localization architecture, static nodes were programmed with known locations and provided location estimation with their own known locations. Based on the signal strength from the surrounding static nodes, the mobile node takes over the location of the closest static node, which is sent along with the tag ID, time and location to the server.

Location information- Static nodes were placed at known locations such as users' workstations, coffee as well as printer locations. Post –processing of the obtained data as depicted in figures 7 & 8, shows that participants were only at their workspace for less than 70% through the duration of the study. For about 30% of the time spent within the office building, participants were at other locations. An interesting discovery however, was the fact that even at these periods when occupants were at other locations, the energy consumption of

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building appliances and systems as depicted in figure 8 remained unchanged.

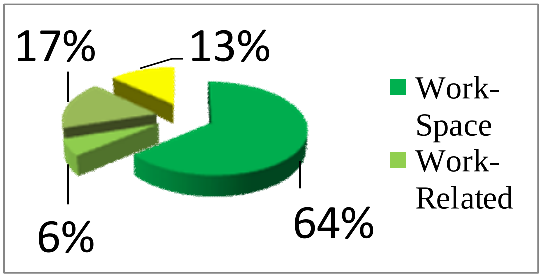

Figure 7: Occupancy Distribution

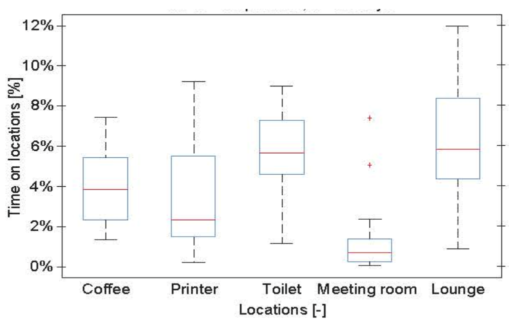

Figure 8: Percentage of time participants were present at other locations

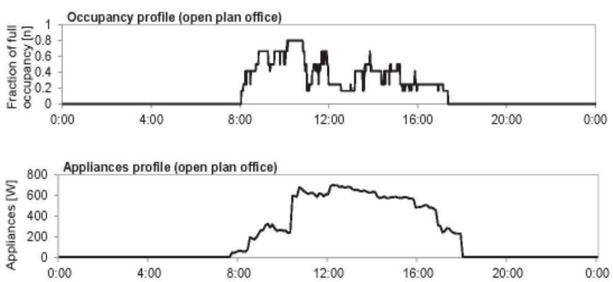

Figure 9: occupancy and appliance energy use

Presence information- Each of the participant had a mobile node on their person thus making it relatively straight forward to determine their presence at each location**.** Post processing results did however show that the average presence was below 60% for this particular office building for the duration of the study. Other similar studies have also shown that average presence in buildings is using less than 70% even at periods of peak occupancy [13, 14, 34].

Count Information- Since each occupant was with a tag, establishing the number of participants was also a relative easy task. It was however observed that participants did at some point forgot to make use of their tags.

Identity- Each participant was assigned particular nodes, which also had unique ID's used to distinguish different participants.

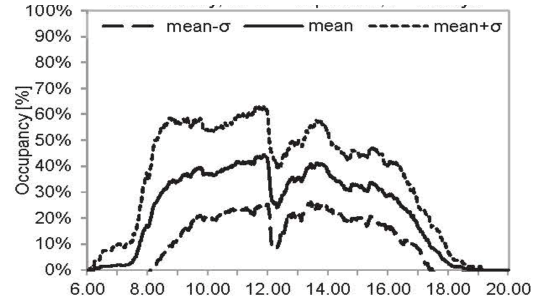

Figure 10: Mean Occupancy.

Track- participants locations as depicted in figure 8 was obtained through post-processing of the data sent to the server from the receiver nodes.

V. DISCUSSION

As shown through the implementation of the client/server localization architecture, obtaining information on track, activity as well as location would require so more network resource if it is to be used for demand-driven control applications in building operations in particular for control of HVAC systems. Utilizing the distributed and autonomous properties of MAS as well as the described MAS based architecture does however reduce the overhead. Since nodes have more autonomy and can exchange information with other nodes, obtaining tracking and presence information utilizes minimal network resources thus making the WSN more robust.

VI. CONCLUSION AND FUTURE WORK.

In this paper, the framework for a multi-agents coordinated occupancy detection system for demand-driven control applications in building to improve buildings energy efficiency as well as responsiveness to the smart grid was presented. The framework described uses a different approach from the conventional client/server network architecture commonly for localization in wireless sensor networks. Initial experimental result from a test-setup in an office building using the typical client/server WSN architecture was presented. The proposed MAS based system is currently under development and would be implemented in the test-bed office building. Its performance would be evaluated with results obtained from the client/server WSN model.

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Model-based Optimization of Lead Configurations in Deep Brain Stimulation

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***Abstract*—Deep Brain Stimulation (DBS) is an established treatment in Parkinson's Disease whose underlying biological mechanisms are however unknown. Mathematical models aiming at a better understanding of how DBS works through the stimulation of the electrical field inside the brain tissue have been developed in the past years. This study deals with *in silico* optimization of the stimuli delivered to the brain using actual clinical data and a Finite Element Method (FEM) approach. The goal is to cover a given target volume and limit the spread of the stimulation beyond it to avoid possible side effects. The fraction of the volume of activated tissue within the target and the fraction of the stimulation field that spreads beyond it are computed in order to quantify the performance of the stimuli configuration. First, a state-of-the-art lead is considered, in both single active contact and multiple active contact stimulation scenarios. A comparison with a field-steering lead is further presented. The obtained results demonstrate feasibility of multiple contact stimulation through better shaping the stimuli and effectively using field steering.**

Keywords–Deep Brain Stimulation; Optimization; Convex optimization; Field Steering; Parkinson Disease

I. Introduction

Deep Brain Stimulation (DBS) is a neurosurgical procedure that consists of delivering electrical stimuli, usually rectangular biphasic pulses, to a target inside the brain by using one or several surgically implanted leads. The goal of the therapy is the alleviation of symptoms of various neurological diseases, such as Parkinson's Disease (PD) [1], epilepsy [2], dystonia [3], and others. DBS mostly replaced surgical lesioning and ablation procedures because of its reversibility, flexibility, and individualization potential [4]. The interest in DBS has spread to other areas of medicine, e.g. psychiatry, with applications in diseases such as schizophrenia [5] or Tourette Syndrome [6]. In the case of PD, since the surgery of DBS is quite complicated and costly compared to treatment with drugs, physicians usually choose advanced patients for this procedure when pharmacotherapy, in particular with levodopa, has lost effectiveness or has severe side effects [1]. Although some studies suggest that an earlier implantation could be beneficial [7].

The principle of DBS is in delivering mild electrical pulses via a chronically implanted lead, whose active contacts are in the subcortical area, where a target area is defined. Prior to the operation, patients undergo clinical examination by a multidisciplinary team, as well as medical imaging. Based on the images, the physician pinpoints a target area, which is in PD usually located in the basal ganglia area of the brain, with the subthalamic nucleus (STN) being of particular interest. A few weeks after the surgery, the patients undergo a lengthy trial-and-error programming period to tune the stimuli delivered to the brain.

The physiological mechanism of DBS and its long-term effects on the brain still remain unknown, and the therapeutical outcome is difficult to predict. Furthermore, because of uncertainties in the position of the leads or improperly tuned stimulation settings, the stimulated volume might go beyond the target causing undesirable side effects [8]. Shaping the stimuli so that the stimulated volume covers the intended target and does not spill outside of it is thus important for maximization of the therapeutical benefits and minimization of the side effects.

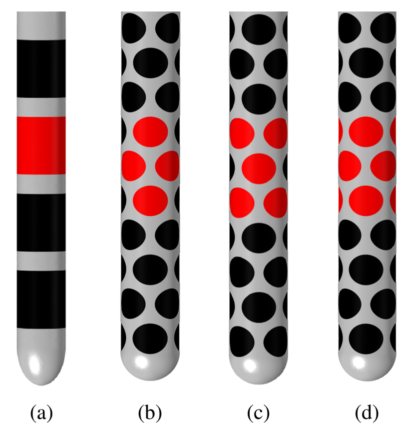

Figure 1. Lead configurations for the conventional lead (a), field-steering Diamond-4 (b), X-5 (c) and X-8 (d). Active contacts are marked in red.

Currently used lead designs, mostly from Medtronics (see Figure 1(a)), were originally adapted from cardiac pacing technology and have not evolved much since then. Meanwhile, the insights into neurostimulation and field steering obtained in recent years through Finite Element Method (FEM) based multiphysics simulation and neuron models, along with the exponential improvement of computational capabilities, open up for more sophisticated and individualized solutions, aiming to shorten the programming time and to better understand the underlying mechanisms [9].

Addressing the shortcomings of the currently used designs, novel leads have been developed by companies, such as 3Win (Belgium), Sapiens (The Netherlands) or Aleva (Switzerland), which could be configured in more versatile spacial settings, taking advantage of field steering techniques to tune the stimuli. As seen in the contacts of the leads shown in Figure 1, while the conventional state-of-the-art lead delivers a radially symmetric stimulation over the whole cylindrical contact, the field steering one is capable of asymmetrical stimulation that can be tailored to the target area anatomy [10].

A possibility for performance improvement in the existing state-of-the-art electrodes is offered by a multicontact approach, i.e. manipulating the stimuli simultaneously using two or more active contacts. It has the benefit of allowing further shaping of the activated tissue area and thus providing more flexibility.

This manuscript is composed as follows. In Section 2, an overview of the FEM mathematical model is given, along with different neuronal stimulation quantification schemes. Afterwards, the optimization technique used is presented. In Section 3, the results of the optimized stimuli are outlined, for a single active contact, for multiple active contacts, and using field steering lead configurations. Conclusions, limitations, and future work are discussed in Section 4.

II. Models and Methods

A. Electric Field Model

The first step to compute optimized stimuli is to obtain the electric field distribution for a given electrode geometry. The electric potential is obtained by solving the equation of steady currents in the tissue:

$$\nabla \cdot (\sigma \nabla u) = 0, \tag{1}$$

where u is the electric potential, σ the electric conductivity, and ∇ is gradient. The electric field $\mathbf{E}$ is obtained by taking the negative gradient of u:

$$\mathbf{E} = -\nabla u. \tag{2}$$

Model (1) can be solved numerically using a FEM solver. The model geometry considered in this study consists of the bulk brain tissue, the lead, and an encapsulation layer surrounding it.

The bulk tissue is represented as a cube with a side of 0.4 m centered on the tip of the lead that is grounded on the outer surfaces to simulate the ground in the implanted pulse generator. Although the brain tissue is heterogeneous and anisotropic in reality, these effects are beyond the scope of this paper, see [9][11] for details. Although the brain tissue has several components, e.g., white matter, gray matter, cerebrospinal fluid and blood vessels, its conductivity can be approximated as homogeneous with $\sigma = 0.1\ S/m$ [12].

Two lead designs were considered for this study: a widely used state-of-the-art lead and a field steering lead. The former has cylindrical contacts with a height of 1.5 mm and a separation between contacts of 0.5 mm. The latter has elliptical contacts. To facilitate field steering, the rows are rotated 45 degrees to each other with respect to the lead axis, as shown in Figures 1(b),1(c), and 1(d). Both leads have a diameter of 1.27 mm.

An encapsulation layer is formed around a lead implanted in the brain due to the reaction of the body to a foreign object [13]. Its thickness and conductivity are still open to debate and might be patient specific. Following [9], a 0.5 mm thick layer with a conductivity of 0.18 S/m is considered.

The stimulation is modeled as a boundary condition at the active contacts surface while the non-active contacts are left floating. It should be noted that model (1) is a linear partial differential equation, and thus, it is enough to compute the field distribution for a unit stimulus and then scale it accordingly, which transformation will simplify the computations.

The model has been implemented in COMSOL 4.3b (Comsol AB, Sweden). The solutions obtained by the FEM solver were then equidistantly gridded on a $70 \times 70 \times 60$ grid centered at the lead tip and expanding 16 mm in the axes perpendicular to the lead and 20 mm in the lead axis, in order to be exported for further processing.

Several field distributions were computed:

- State-of-the-art lead: Distributions with one active contact and the rest floating were computed at first. In addition to that, field distributions with the grounded inactive contacts were computed. This was done to enable summing up them for the multicontact approach, since the effect of one active contact on the others when left floating can be computed.
- Field steering lead: Distributions for the different configurations considered (Diamond-4, X-5, X-8, shown in Figure 1) were computed for each row of contacts.

B. Quantification of activated volumes

Volumes of activated tissue can be quantified by using axon models under the methodology by McNeal [14]. While axon models yield precise results, the procedure is computationally expensive and the neuron network must be known to some degree. Other approaches involve functions that approximate the activated volume without taking into account the anatomy of the neurons, such as Rattay's activation function [15] or the electric field. These have the advantage of requiring less computations and only a stationary analysis. However, using second derivatives might result in numerical issues, in particular in the area near the lead. Furthermore, it was shown that the electric field provides more robust means for quantifying neuronal stimulation [16]. Thus, for this study, the electric field will be used. The activated neurons are distinguished from the rest by applying a threshold value to the electric field that will depend on the neuron anatomy and the characteristics of the pulse itself [16].

To place the pre-computed by the FEM solver electric field at the proper position, conventional translation-rotation algebra is utilized. Assuming that the tip of the lead is at the origin, the set of operations is given by:

$$\mathbf{E}_{\text{eval}} = R_{\text{rot}} R_z \mathbf{E} + \mathbf{x}_{\text{lead}}, \tag{3}$$

where $\mathbf{E}$ and $\mathbf{E}_{\text{eval}}$ are the original and positioned electric field vectors respectively, R_{rot} is a rotation matrix which aligns the field with the given lead vector, R_z is a rotation matrix with respect to the Z axis (used for field steering), and $\mathbf{x}_{\text{lead}}$ is the lead position.

Once the field is properly positioned and filtered with the aforementioned threshold, intersection volumes are computed under a methodology similar to [17]. Two of them are of particular interest: the activated volume of the target area and the activated volume outside the target area. The topology of the target area is taken from an atlas of potential regions for therapeutical stimulation and can be assumed to be convex. Whether the electric field points are inside of the convex hull of the target area or not is checked with an additional function [18].

C. Optimization scheme

In order to optimize the stimuli, the following optimization problem can be defined:

$$\min_{u_i} \ J(u_i), \tag{4}$$

where u_i are the optimization variables (in this case, the electric potential or potentials of the stimuli) and $J(u_i)$ is a cost function to be defined (ideally, a convex function).

The following cost function is proposed:

$$\begin{aligned} J(u_i) &= p_{\text{Spill}}(u_i)\left(\frac{100-p_{\text{Act}}(u_i)}{100-p_{\text{Th}}}\right) \quad && p_{\text{Act}} \leq p_{\text{Th}} \\ J(u_i) &= p_{\text{Spill}}(u_i) && p_{\text{Act}} > p_{\text{Th}} \end{aligned} \tag{5}$$

where p_{Spill} is the fraction of the activated volume that lies outside the target, p_{Act} is the fraction of the target which is activated and p_{Th} is the minimum activation required of the target. All of them are given in percent for illustration. For this study, p_{Th} is set at 95%.

The motivation behind the cost function above is that it is continuous and convex, since both p_{Act} and p_{Spill} are monotonically nondecreasing with the amplitude of the stimulus. An example of cost function (5) dependence on the stimuli amplitude can be seen in Figure 2.

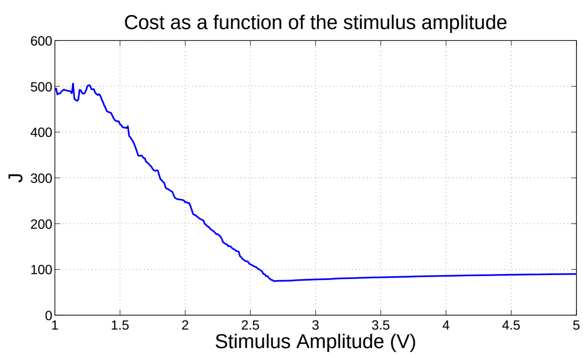

Figure 2. Example of cost function J as a function of the stimulus amplitude

The small peaks that appear in Figure 2 occur because of issues with the volume computation. They arise since the geometry used for both the activation volume and the target is defined in convex hulls of a discrete cloud of points. Although this makes the function non-convex in practice, the peaks are small enough to be skipped by increasing the step size of the optimization algorithm. A minimum step size of 0.002 V was taken.

III. RESULTS

A. Single Contact

To optimize stimulation with only one active contact, two approaches can be considered. First, the contact can be fixed and only the stimulus amplitude is optimized. Second, the active contact is left as an additional optimization variable, restricted to taking a single value in the set $C_s = \{0, 1, 2, 3\}$, where contact 0 is the most distal and 3 is the most proximal. Due to the possibility of choosing the active contact at will and to illustrate the efficiency of the optimization method, the second approach is selected in this study.

The free contact approach will divide the optimization into four problems with fixed contacts. In order to speed up the computations, best active contact could be chosen without optimization. By examining $J(u_i)$ given by (5), it can be easily seen that as long as there is an intersection between the activated volume and the target for at least one of the contacts, the cost function will be lower in general for the optimal contact no matter how big u_i is. So, it is enough to do a single evaluation of the cost function for a given value of u_i to choose the contact. Said value cannot be too low, since it might yield empty intersections, or too high since it will take too much time to calculate due to the number of points involved. Thus, the evaluation is performed with low u_i and then if the intersection is empty, u_i is set to a higher value.

Optimization was performed for 65 lead positions whose clinical data stated a single contact stimulation with an activation threshold of 175 and 200 V/m for comparison. Comparing the results with respect to the clinical settings is of great interest, so the fraction of configurations estimated successfully by the optimization algorithm with respect to the clinical settings was computed as well.

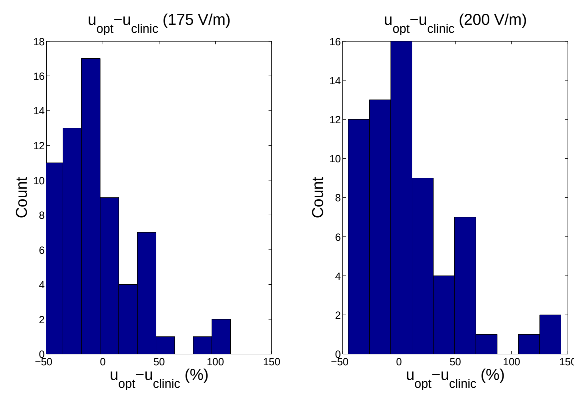

Figure 3. Discrepancy of amplitude for 175 and 200 V/m

TABLE I. SINGLE CONTACT OPTIMIZATION

Threshold: 200 V/m	
Correct contact (%):	53.8
1 contact error (%):	35.4
Discrepancy of amplitude (%):	9 ± 41
Threshold: 175 V/m	
Correct contact (%):	50.7
1 contact error (%):	38.4
Discrepancy of amplitude (%):	-4 ± 35

It can be seen from Table I that the mathematical model and the defined target predict the clinically used contact in roughly a half of the cases. In addition, in almost all of the cases, the predicted optimal contact is an immediate neighbor of the one specified in the clinical data. In some cases, there is no significant difference in the values of the cost function, so either contact can be utilized, according to the calculated

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values. In addition, the predicted optimized stimuli amplitude is fairly close to the clinical one (see Figure 3, which suggest that in most cases a threshold between 175 and 200 V/m might be sufficient. It comes though with a high standard deviation.

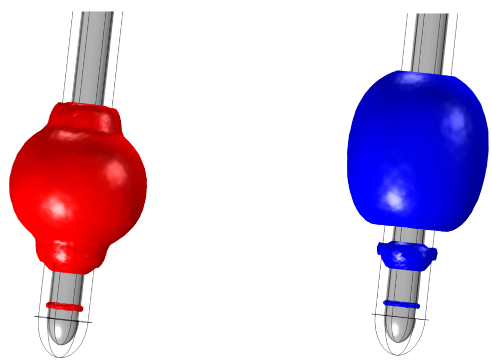
B. Multiple Contacts

Another approach would be to allow for multiple active contact configurations. To simplify the field modeling, the linearity of (1) is exploited. In particular, the field distribution for each contact stimulating with an unit stimulus while the others are grounded is computed first, denoting it as $\mathbf{E}_{0,i}$ for the i-th contact. Then the relation between active contacts and the rest in floating configuration is computed. It follows a linear relationship and is denoted as α_{ki}, which would represent the effect the i-th contact has over the k-th contact when the k-th contact is floating. This is used to transform from an active-grounded to an active-floating configuration, when the contributions are being summed.

The electric field distributions result from a sum of four contacts, with the stimuli given by the active contacts, denoted by u_i and representing the degrees of freedom and the non-active (floating) contacts contributing with the terms characterized by the corresponding α_{ki}. For example, for a 2-contact scheme, one gets

$$\begin{aligned}\mathbf{E}_{2cont}(\mathbf{r}) &= u_1\mathbf{E}_{0,1} + u_2\mathbf{E}_{0,2} + \\ &+ (u_1\alpha_{31} + u_2\alpha_{32})\mathbf{E}_{0,3} + (u_1\alpha_{41} + u_2\alpha_{42})\mathbf{E}_{0,4}\end{aligned} \quad (6)$$

It should be noted that the numbering of the contacts above was arbitrary, and it could be any combination of them.



(a) (b)

Figure 4. Isolevels for $E = 200\ V/m$ for a single active contact (a) and two active contacts (b)

As can be seen in Figure 4(b), multiple active contacts might be useful to tailor the stimulation so that it achieves a similar activated volume with less overspill. The results is in principle dependent on the position of the target with respect to the active contact in the single contact approach. If the target is located next to the active contact, then it would be probably more useful to consider just a single contact stimulation. However, if the target is located in between two contacts, shaping the stimulation with these two contacts might be beneficial.

The optimization method is similar to the one described in the previous section for a single contact. To speed up computations, only the configurations which involve neighbouring contacts to the ones obtained in the single contact approach are considered. So, for example, if the optimal contact is contact 1, only combinations which involve contacts 1 and 0 and 1 and 2 are considered (see Figure 5).

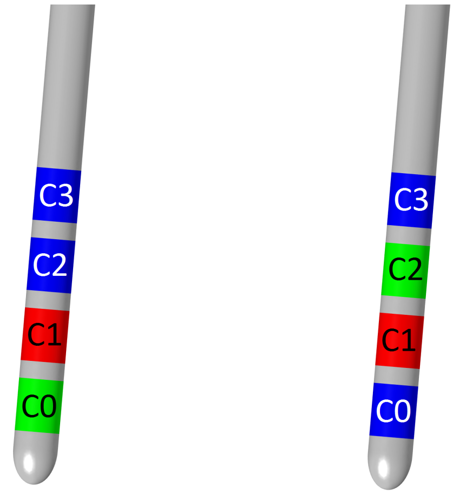


Figure 5. Example of considered multicontact configurations, with Contact 1 as the optimal (in red) and Contacts 0 (left) and 2 (right) as secondary (in green)

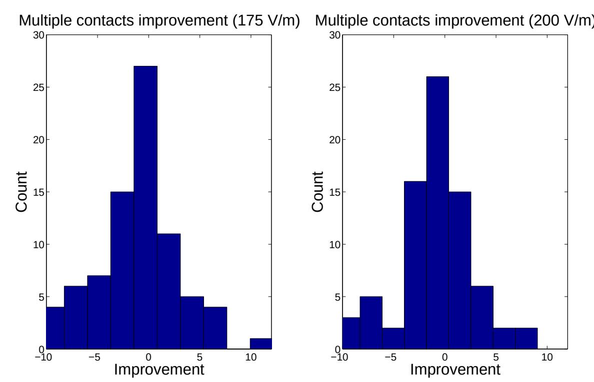


Figure 6. Improvement of overspill for 175 and 200 V/m for the multicontact approach

TABLE II. MULTIPLE CONTACT OPTIMIZATION

Threshold: 200 V/m	
Improvement cases (%):	38.7
Overspill improvement (percentage points):	2.00 ± 2.28
Threshold: 175 V/m	
Improvement cases (%):	37.5
Overspill improvement (percentage points):	2.67 ± 2.83

Results are summarized in Figure 6 and Table II. The improvement is, as expected, situational, and appears only in a part of the cases. However, the improvement can be significant, with a decrease of up to 5 or 6 percentage points in the absolute value of the overspill with respect to the single contact approach. It should be noted that the state-of-the-art lead considered here features a small distance between contacts. Better results could be achieved for larger distances between

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contacts, since it is more likely that the target lies between contacts.

C. Field Steering

As was investigated in [17][19], field steering yields better results regarding overspill than with the state-of-the-art radial stimulation. In this study, the optimization scheme described above was implemented to obtain the optimal stimulus amplitude.

Three different configurations were tested, as illustrated in Figure 1. The parameters to optimize would be, for each configuration, the rows where the active contacts are located and the orientation of the lead with respect to its axis. To speed up computations, the optimization followed a similar scheme to the one with multiple contacts, taking as a baseline the results obtained with single contacts and state-of-the-art lead. Due to different shapes of the contacts, the rows at roughly the same height are considered, plus their neighbors.

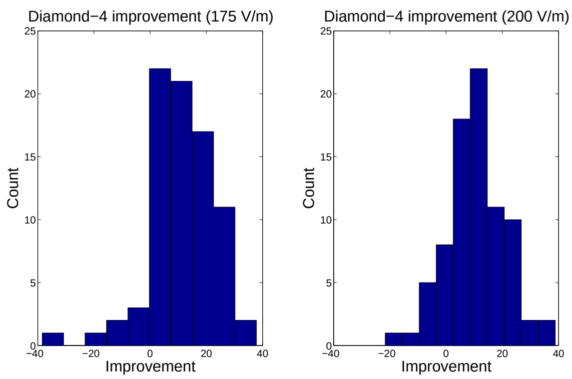

Figure 7. Improvement distribution using the Diamond 4 configuration

TABLE III. DIAMOND 4 CONFIGURATION IMPROVEMENT

Threshold: 200 V/m	
Improvement cases (%):	87.5
Overspill improvement (percentage points):	10.37 ± 10.52
Threshold: 175 V/m	
Improvement cases (%):	91.25
Overspill improvement (percentage points):	11.48 ± 11.63

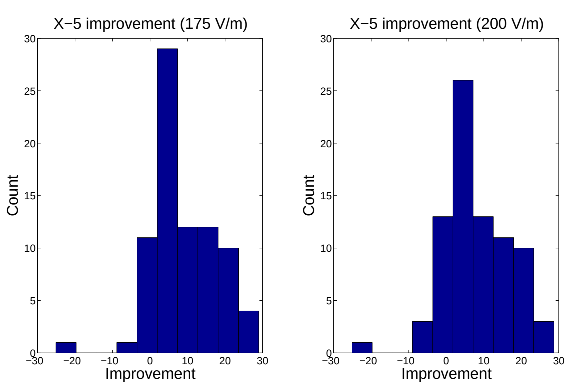

Figure 8. Improvement distribution using the X-5 configuration

Table IV. X-5 configuration improvement

Threshold: 200 V/m	
Improvement cases (%):	88.75
Overspill improvement (percentage points):	8.65 ± 10.67
Threshold: 175 V/m	
Improvement cases (%):	92.5
Overspill improvement (percentage points):	9.76 ± 10.37

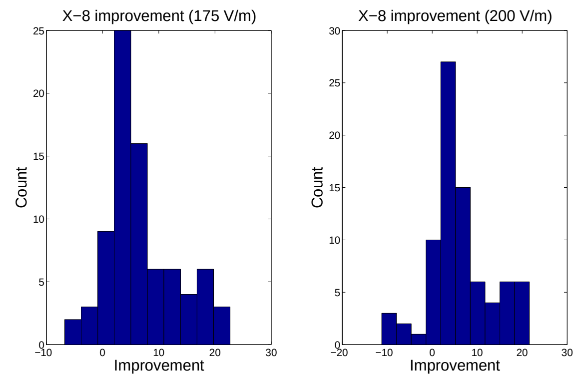

Figure 9. Improvement distribution using the X-8 configuration

Results are summarized in Figures 7 - 9 and Tables III - V. In almost all cases, there is an improvement in the overspill with respect to the one-contact approach. The improvement is largest in average with the Diamond-4 configuration (see Figure 7). The high standard deviation comes from the variety of geometries considered, making the improvement heavily dependent on the lead position with respect of the target. Some cases were observed where the X-5 or X-8 configurations achieved better results that could be because of the lead location.

IV. DISCUSSION

Using optimization schemes in order to scale the stimulus amplitude of the active contact or contacts could yield an activation volume that better covers a given target, limiting, at the same time, as much as possible stimulation beyond the target. This study compares the state-of-the-art one-contact approach with a multiple contact approach and field steering.

In the analysis of the one-contact approach, it was seen that selecting the active contact freely for a given target, a simple model predicts the clinically used contact in roughly a half of the times in the considered lead population. Furthermore, in some cases, there is no significant difference between the scores of the clinical and the optimal configurations.

In the multicontact approach, allowing for multiple contacts improved the overspill in around 38% of the cases. It must be noted that the effect is limited by the small distance

Table V. X-8 configuration improvement

Threshold: 200 V/m	
Improvement cases (%):	90
Overspill improvement (percentage points):	11.51 ± 10.63
Threshold: 175 V/m	
Improvement cases (%):	91.25
Overspill improvement (percentage points):	11.56 ± 10.41

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between the contacts and could be more significant for a larger separation of the contacts.

Finally, the results obtained are compared to field steering configurations. A significant improvement of the overspill with a decrease of 10 percentage points in average was found in all cases, with an average decrease of 18 percentage points for the Diamond 4 configuration.

However, the results obtained in this study are valid under some limitations. First, the brain tissue was assumed to be homogeneous, when this is not the case and significant (patient specific) differences may arise [9]. Furthermore, the encapsulation layer surrounding the lead has uncertain physical properties, such as the conductivity and the thickness, both of which might be time variant [20]. In addition, considering the electric field as a predictor of whether a neuron is stimulated or not is an approximation. A more thorough analysis would need a complete neuron population model. Finally, the results obtained assume a certain target structure, which may be patient specific as well. Results should be verified against therapeutic outcomes, but the latter are not yet available for this study.

Despite the mentioned limitations, this study highlights how using optimization schemes and geometric arguments can help to choose optimal stimuli and facilitate the comparison between different configurations. Further work could add more optimization schemes, such as using electric field differences between a target electric field distribution and the one given by the lead instead of geometry. In addition, it would be worthwhile to study the influence of the encapsulation tissue properties and the anisotropies of the brain tissue.

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Smart City Framework based on Distributed Mobile Devices System Design and Implementation

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***Abstract*—Smart Cities and smart services delivered by them are considered a new paradigm in computer engineering. Due to the daily increase in usage of portable smart devices, as smartphones or smartwatches, which provide different sensors and connectivity facilities, they were used to design a framework and implement a wide-area network with distributed nodes in order to provide continuous and non intrusive interaction with various urban facilities. We focus on three main modules: hybrid human localization (Indoor and Outdoor) using Bluetooth Lite Energy (BLE), GSM (Global System for Mobile Communications), GPS (Global Positioning System) localization and the Smart City Framework (SCF), which handles interaction with various external services (i.e., transportation organization, municipal and traffic authorities). The communication between the two aforementioned modules is done via a mobile application, which interacts directly with the user and the remote SCF framework itself.**

Keywords*—*Assistive technology; Smart City; Mobile computing; Smart homes; Wearable computers; Helping services; Internet of things.

I. INTRODUCTION

More than half of the worlds population lives in urban areas. The growth of population, which needs various urban and social services, due to increase in people aging, causes several problems for the society [1]. In this case, Smart Cities are suggested as a partial solution for the new era metropolitan areas. As of today, there are several definitions for smart cities, which analyses and groups them according to different aspects of their study.

- A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, railways, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens [2].
- A city connecting the physical infrastructure, the IT (Information Technology)infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city [3].
- A city combining ICT (Information and Communication Technology) and Web 2.0 technology with other organizational, design and planning efforts to dematerialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability [1].
- The use of Smart Computing technologies to make the critical infrastructure components and services of a citywhich include city administration, education, health care, public safety, real estate, transportation, and utilitiesmore intelligent, interconnected, and efficient [4].

The common property in these definitions is the presence of an IT backbone which interconnects and communicates with the various parts and modules of a Smart City, in order to benefit its citizens with a unified framework and handling optimally all social needs present in the city. Meanwhile, mobile and wearable devices are becoming much more available and popular, as they are integrating various hardware/software capabilities on a single device. Integration of different services and smart devices opens several opportunities for citizens which could hardly be achieved, if even possible, without using them. As an example, a blind citizen registered in the system can trigger the street light and stop the traffic on an intersection just by standing near the sidewalk and receive a confirmation on his/her device about the moment when it is safe to cross; also, the street light could be notified about the moment when the person is far and safe enough in which to switch back the light to green for cars. We can also imagine an elderly traveling underground in a subway line. The smart city framework will be capable of notifying the person prior to arrival at the place and the time of getting off. To achieve the desired goals, there is a need for a localization scheme, which offers indoor and outdoor localization. Currently, GPS and GLONASS (GLObal NAvigation Satellite System) are considered as the diffused outdoor localization technologies. GPS, and similarly GLONASS, which uses a similar technology, are attractive options for outdoor environments, but are not suitable for indoor applications because they need a clear line-of-sight to orbital satellites in order to track position. This requirement makes them unsuitable for indoor uses, and a different approach must be taken for indoor localization. Several solutions have been developed in research, implementing different techniques as use of RF (radio frequency) signals, WiFi localization, ZigBee, etc. Most RF solutions are sensitive to the number of humans present in the environment and use proprietary and/or expensive components with high power consumption [5]. Another common issue in indoor localization systems is peer2peer communication between nodes, which is a problem in urban areas due to the high number of nodes and

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the distance between them, which limits reach of a node with its neighbours. Bluetooth has been used among other Radio Frequency (RF) technologies for indoor localization since it is a cost effective and easy-to-deploy solution [6] with an open core specification [7]. In this paper, we propose a Bluetooth Low Energy (BLE) localization solution integrated with a Smart City backbone framework. The proposed localization solution has a low cost (8.5 USD per node). It is easy to deploy as it does not need node configuration, and it has a high battery autonomy (from 20 months up to 6 years depending to the battery type used). It is built with commercial off-the-shelf (COTS) components. The Smart City backbone framework is a modular system, which handles both data storage and reasoning based on available data it receives by its clients. The system is based on distributed servers, which are divided per zones for increased efficiency, while continuously synchronizing data between each other. In this work, first we discuss the general system architecture, then in Section III we describe our hybrid indoor/outdoor localization. Following, in section IV, we talk about the framework backbone and its design. Also the services provided by the framework are discussed. In Section V, the client side application is explained. This application is responsible for the communication between the server and the user. In Section VI, we discuss about power consumption issues and solutions provided by our system and finally, in Section VII, we discuss experimental results, and conclude in Section VIII with a brief overlook to the work.

II. System Overview

The system is based on three separated modules. The first module discussed, the localization system, has been specifically developed for this work. This module, by itself, is based on two separated localization systems. Outdoor localization, which in our case is GPS, and indoor localization system, which has been developed based on bluetooth low energy modules. These two outdoor/indoor localization systems combine together to form a hybrid system capable of continuous localization whether outdoor or indoor. The second module is the Smart City Backbone Framework, which acts as the central server and processes the received data, handles storage and reasoning and integrates the services offered by third party providers. It is a distributed application, which is installed and running on multiple servers. This is to avoid network slowdowns for the occasions in when it experiences high network traffic. These two modules communicate together using mobile applications installed on smartphones, which is considered the systems third module (client side application).

III. Localization

The localization method will be studied for a hybrid setting, including both indoor and outdoor environments. BLE transmitters will have known positions registered on the server and BLE receivers without known positions. In our test case, two Bluetooth 4 low energy android devices (OnePlus One and Motorola Moto G), will act as BLE receivers moving freely among them, carried by users. There are different methods for localization such as Cell Identity (CI), Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), and received power level based localization. All of these methods have their own advantages and disadvantages, but in general received power based method may be considered as an easy way to do localization, considering both hardware and software requirements [8]. The main problem with RF techniques in indoor environments is that physical obstacles absorb the signals and cause RF techniques to be unreliable for indoor measurements[5]. Bluetooth devices measure the received power level indirectly by using RSSI (received signal strength indicator), which is a measurement of the power present in a received radio signal, and it is implemented in the Bluetooth module and can be read easily [6]. Consequently, the received power level based localization seems to be the most applicable one for Bluetooth [9]. As mentioned previously, as any RF signal, we experience the problem of power absorbment by physical obstacles. To handle this situation, we have converted our measurement values from a continuous system to a discrete system with a three level threshold, which are: Immediate (below one meter), Near (above one meter and below 10 meters) and Far (more than 10 meters). The accuracy of the wireless localization systems relies heavily on calibrated distance metrics. Using RMSE (root-mean-square error) is a good choice due to availability and relatively stable performance it provides [9]. In our case, each BLE node, broadcasts its UUID (universally unique identifier), Bluetooth MAC address, transmit power (txPower) with a frequency of 0.1 Hz and a major-minor pair, which are used to uniquely identify a node. Similarly a UUID is used for uniquely identifying information. It identifies a particular service provided by a bluetooth device. RSSIs are calibrated according averaging for 60 seconds at a distance of 1 meter. Measuring various RSSI's at known distances, we did a best fit curve to match our data points. A node was installed within 1 meter from the mobile smartphone, which was acting as a receiver. The txPower was set to the maximum available by the BLE module and the RSSI of the signal was measured. The measured value was set as the txPower for the node. At this point, for various distances (0.5 m, 1m, 2m, 3m, 10m, 12m and 20m) the RSSI was measured. Over a 20 second average, we applied a filter removing the 10% top and bottom values that resulted a stable trade off. At last, we fitted a best fit curve and obtained the following equation in java code:

```java
double ratio = rssi*1.0/txPower;
distance = (0.89964)*Math.pow(ratio,7.7083) +
    0.112;
```

Each node, operates in an advertisement mode to notify the nearby devices its presence by using advertisement frames. An example advertisement frame could be as following:

```
ch1d64v5-4578-26 bv-327f-85j955go12a6 Major 1
    Minor 2
```

As presented in Figure 1, each mobile device, receives one or more beacons from surrounding nodes. It initiates a session with the server using a secure SSL connection in order to prevent unauthorized access and faking users. Because of the architecture of BLE, nodes could be easily forged by cloning UUIDs, Major/minor and macs. To prevent this, the server keeps a log of the previous node locations sent by each mobile client, in order to detect any anomaly, as duplicates or sudden jumps to locations far apart. At this point, it calculates the estimated distance, and communicates it to the Smart

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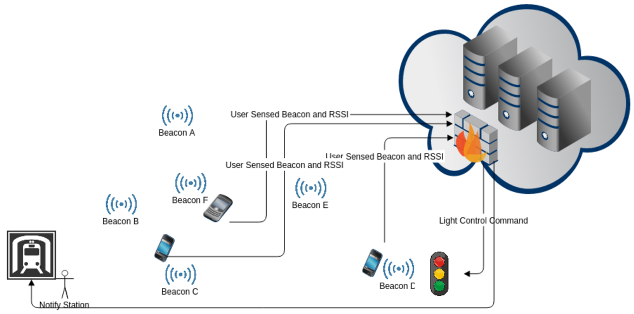

Figure 1. Smart City Framework Architecture

City server, binding it with any available GPS data for more precision and robustness against frame cloning.

IV. Smart City Framework Backbone

The Smart City Framework (SCF), as mentioned before, has the objective of processing, storing and triggering different service actions. It is composed of three separate entities: Event Handler, Condition processor and Action unit as in Figure 3. Events are generally BLE beacons combined with user IDs and optional GSM data packets such as CID (cell-ID), MCC/MNC (mobile country code/mobile network code), LAC (Location area code) network and signal strength and GPS acquired position when available (outdoors). The cell-ID is the unique identification number of the GSM cell tower (aka GSM base station, Base Transceiver Station) the phone is currently connected. MNC is a number used to uniquely identify the GSM network provider in combination with the MCC. MCC is a unique country code of the GSM network the phone is currently connected to. The SCF, after receiving a BLE event, it stores it into its database, which is consequently compared and mapped with nodes available in it, finding the closest nodes and an estimate of the users position through trilateration by using their signal strength as in Figure2.

Through the BLE RSSI, the SCF will be able to categorize the user location within a three distinct ranges:

- Immediate: Within a few centimeters
- Near: Within a couple of meters
- Far: Greater than 10 meters

The SCF has the ability to determine whether a user has entered, exited or remained in a region through RSSI level changes. For example, if a received signal starts to loose power through time (and not peaks), it indicates that a user is getting further from the base station. On the other hand, if a received signal is getting stronger, it indicates that a user is getting close. Power peaks or looses, that are less than the time frame defined by the mobile application, are opted as they could be due to sudden signal absorbment by passing objects, humans, etc. and not a user behavior. Each received beacon is considered separately according to the user which has submitted it and the services subscribed. The SCF will decide whether it needs to invoke an external service (i.e., switching a traffic light at a certain intersection), notify the user about an event or neglect it. External services are available to SCF by mean of a REST (Representational State Transfer) API. In this way, SCF is capable of notifying or

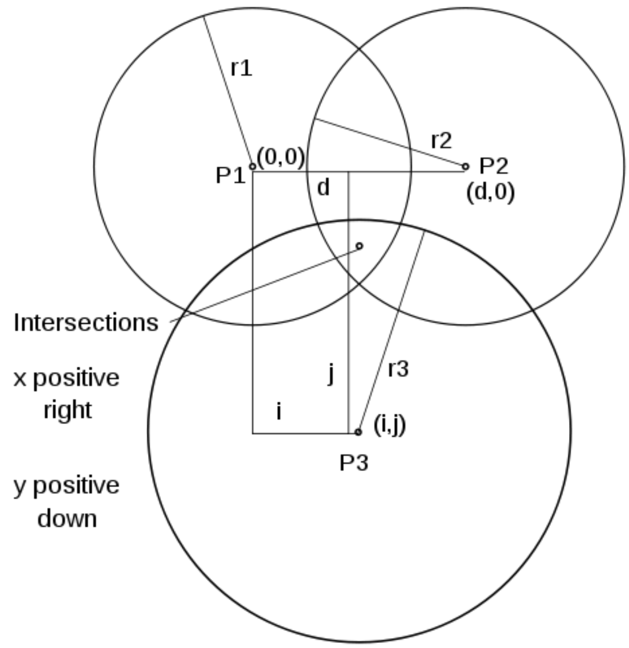

Figure 2. The two intersections of the three sphere surfaces are directly in front and directly behind the point designated intersections in the z = 0 plane.

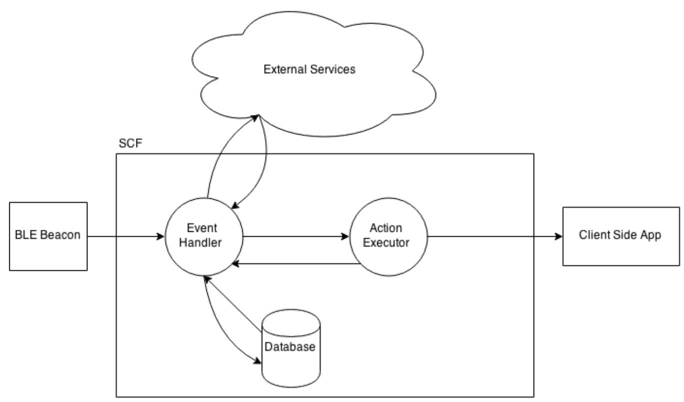

Figure 3. Interactions within SCF

querying services about their current state, change their state and available actions, which are available for a specific user, as sending a push notification or controlling a device.

The system provides a RESTful API, which allows external services, as bus services, metro lines, street lights, hospitals, stores and generally, any city available service to provide their functionalities to the clients. In order to an external service to work with the framework, the framework can provide the following parameters: a user ID, indoor and outdoor location, nearing or distancing state of the user. External APIs could be registered to be triggered according to the desired events by the user. Two different beacon categories are pre registered in the SCF database, Static Beacons and Dynamic Beacons. The Static beacons are used to present data such as location or tags (product tags) and usually are unchanged. Dynamic beacons information in the mapping system, instead could be changed

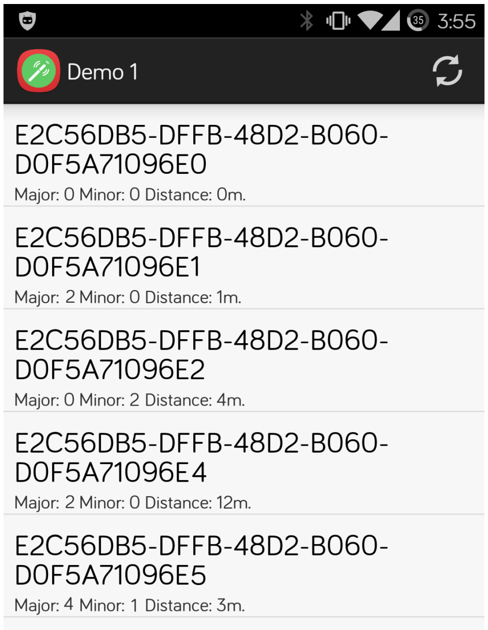

Figure 4. Client Side Application

UUID	MAC	Major
E2C56DB5-DFFB-48D2-B060-D0F5A71096E0	B4:994C4F74A5	0X8810

Minor	RSSI	TX	Optional
0X7401	-77dbm	-59dbm	Optional data

Figure 5. Sample beacon packet received by a client, demonstrating UUIDs, major, minors and clients estimated distance from each

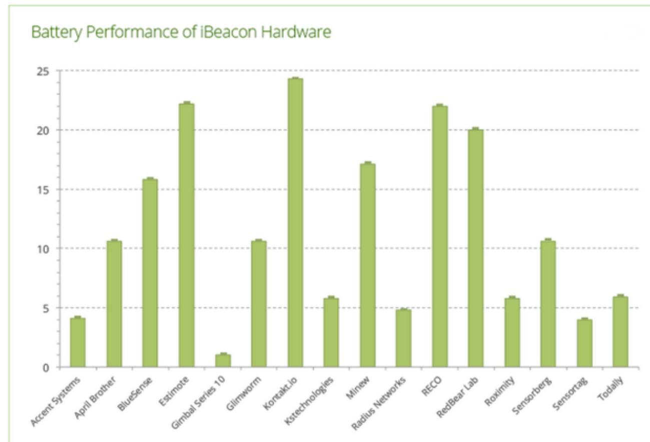

Figure 6. Comparison of 16 major beacon hardware of battery life in months (higher is better) by Aislelabs' The Hitchickers Guide to iBeacon Hardware[11]

Figure 7. BLE node used in this work, a W901 wellcore module

(manually by service provider/automatically according to predefined scheme), which leads to a beacon to provide new data using the same constant BLE data frame.

V. Client Side Application

The client side application was developed using the Android SDK. It constantly scans for BLE advertisement beacons with a scanning window open for 10 seconds each. Proximity for each beacon node is then calculated and it is sent to the remote SCF server for processing along with users authentication keys. If a user is constantly in an environment, while results in no change to the Immediate-Near-Far distant approximation, no data is communicated to the server. The application sends the captured data frames though any available network connection to the the server, whether WiFi, 2G or 3G/4G networks). In the case where the server needs to send a notification to the client app, i.e., an intersection that is safe to cross due to a green traffic light, the mobile app will receive the push message and using android text2speech API, converts it to synthesized human voice. The data frame, which is communicated to the SCF server consists of all the received BLE advertisement packet and optional data, which depending to the use case, could be applied, i.e., cellular IDs or GPS data as mentioned previously in section "Smart City Framework Backbone". A screenshot of the application is seen in Figure 4, which shows the received the beacons, and their distances from the receiver.

VI. Power Consumption

Power consumptions on BLE nodes depends to both advertising frequency and transmit power. A study was done on 16 different BLE module vendors following the iBeacon specification [10]. The report demonstrates that the battery life range could between 1-24 months, as seen in Figure 6.

Also, there are ready to deploy modules with two or three batteries, which their lifespan could range up to 6 years. In our work, during the period of approximately 6 months (163 days), a 17% battery decrease was measured using a third party BLE module provider using a TI(Texas Instruments) cc2541 chip and a CR2477 battery, as seen in Figure 7.

Smartphone power consumption is another aspect which must be mentioned. The application transmits the advertisement frames only when changes are detected, so for example, when a person is in a library, as he/she is constant, no data will be transmitted to the server. Also, in next works, the scanning will take place only when movement is detected by the phones accelerometer module, which draws much less power. During our tests, during a full day of 24 hours, a smartphone (OnePlus One) with a 3100mAh battery, in continuous node scan and sync with server, has used 25% of its battery power for the specific application, measured by the battery manager of Android 5. It can further be improved by implementing a dedicated BLE chip which could scan nodes in deep sleep mode (low frequency).

VII. Experimental Results

To experiment the system structure, a set of 10 BLE nodes were deployed. This number of nodes would be sufficient for trying the system by itself, as the server would be deployed on a distributed cloud, and network traffic would be feasible to handle. All UUIDs, MACs, Major/Minor pairs were inserted into the database. In order to measure the distance with a proper accuracy, each beacon needed to be calibrated prior to use, as mentioned previously. The SCF server was written in Python using Flask micro-framework and later ported to Django for better distributed operation. At this point it was deployed on an Ubuntu Server on a cloud provider, listening to requests sent by the clients. Two test users with smartphones in their pockets (OnePlus One/Motorola Moto G), were allowed to freely move around the area, both indoors and outdoors. According to their movements, events were registered on the server, and connected ZigBee light switches through an external API were automatically turned on and off. At the mean time, a room was labeled as no-enter zone, and registered in the system, as an external service depending solely on location data. While standing by its entrance, a notification was automatically sent to the person alerting them about the prohibition through the vocal interface. The user could call the elevator, enter and get off at the ground floor without any physical interaction with the elevator command buttons, just by entering a zone near to the entrance of it, in order to call it.

VIII. Conclusion

A framework which can interact with users is crucial in order to have a smart city which can provide autonomous interaction and service to its citizens. In this paper, we have proposed and implemented a modular framework backbone, which permits its users to interact with it using their smartphones, and also the possibility of integrating with various services provided by external entities. This can lead to a more autonomous lifestyle for different groups of people living in future smart cities and permitting the governmental organization to automate several aspects of urban activities.

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Smart Shirt with Embedded Vital Sign and Moisture Sensing

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***Abstract*—This paper presents the development of a smart shirt with embedded electrodes in two-lead configuration for heart rate measurement and a knitted moisture sensor for sweat detection. Signal conditioning for heart rate measurement is based on the Analog Devices AD8232 heart rate monitor front-end. The shirt is part of a fireman interactive Personal Protective Equipment (PPE), which monitors information on heart rate and sweat detection, among other variables. Sweat detection is used to avoid skin burns that may occur due to the combination of excessive moisture and heat. Tests have demonstrated that the measurement of heart rate using the shirt is as efficient as conventional solutions, such as heart-rate monitoring straps. Sweat detection through textile moisture sensors has also shown to be effective.**

Keywords-ECG; biosignal; moisture; e-textile; textile sensors.

I. INTRODUCTION

Textiles are excellent interfaces for bio-signal sensing, as they are flexible, stretchable and conform to the body. People use textiles daily and at all times, rendering them an interesting solution for ubiquitous, continuous health monitoring [1][2]. With the remarkable emergence of embedded textile sensors, the proposal of e-textile solutions has grown significantly, empowering the development of new designs to provide a better user-experience. This growing area values comfort and mobility of health monitoring devices. Nowadays, it is possible to seamlessly integrate sensors and electrodes into the fabric's structure of a clothing piece to monitor elderly people, sports or hazardous occupations. The complete integration of these sensing elements and connections into the garment structure represents a great advantage to the physical and psychological comfort of the user.

Several works proposed breathing rate and movement monitoring using extension sensors based on knitted fabrics produced with textile compatible conductive yarns [3]-[7], as well as, with specially made rubber coatings doped with carbon fibers and/or conductive polymers [8]-[11]. Electrodes for physiological signal sensing, such as Electrocardiography (ECG), Electromyography (EMG) or skin impedance have been developed and demonstrated [12]-[18]. Moisture sensing using textiles has been proposed in [19].

Textile-based sensors integrated into a shirt for PPE have been developed in the Proetex project [20] to measure heart and breathing rates in firefighting situations. Breathing rate was measured using two techniques: piezoresistive textile extension sensors and thoracic impedance measurement.

In this paper, the behavior of ECG electrodes and moisture sensors based on conductive yarn knitted in a shirt of an interactive PPE is evaluated and analyzed. The analysis focuses on two different components: the heart rate measurement with two leads and the moisture sensing with two conductive pads. The combination of temperature and moisture sensing is implemented for the detection of situations in which danger of skin burn exists. The shirt is one of the components of an integrated system in which temperature, movement, position and alarm signals are transmitted from/ to the firefighter interactive PPE.

After the introduction and review of the state-of-the art given in Section I, Section II focuses on the development of the shirt, describing materials used, the shirt's design and production. Section III gives an overview of the signal conditioning hardware developed for the measurement of the heart rate and moisture sensor. In Section IV, results of the measurements are presented and discussed, and some conclusions are drawn in Section V.

II. SHIRT DESIGN

A. Materials and Design

When considering wearable devices, strict requirements on volume, weight and energy use exist for optimal effectiveness. Therefore, the decision for a two-electrode configuration for the heart rate measurement was straightforward, considering that the goal was not the acquisition of the full ECG complex. In terms of shirt design, this also meant a reduction of the number of connection paths, and the possibility of placing the front-end hardware closer to the heart, making the system more robust and less vulnerable to common-mode interference.

The electrodes are knitted into the base-fabric using a silver coated textured polyamide elastic yarn from Elitex, produced by TITV, with low electrical resistance (in the order of tens of Ω/m).

The moisture sensor consists of two conductive parallel bars, knitted in the shirt using the Elitex yarn. The change of moisture absorbed/dispersed by the non-conductive textile substrate between the two bars produces a resistance change that is detected by appropriate hardware.

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B. Production

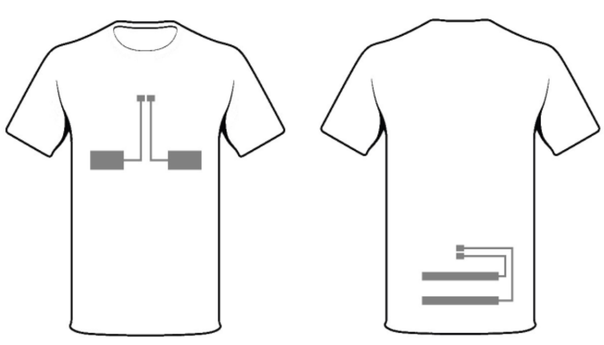
The shirt is knitted in a seamless MERZ MBS knitting machine. This machine allows knitting patterned structures through local variations of the structure, which were used to knit the electrodes for heart rate measurement, the conductive bars, for moisture detection, as well as, conductive leads to connect these elements to the conditioning hardware. For the electrode area, a particularly voluminous structure was developed that makes the electrode area stand out of the rest of the fabric and thus improves skin to electrode contact [21].

To assure the correct positioning of sensors and signal acquisition hardware, the optimal electrode and sensor arrangements were studied.

Regarding the electrodes for the heart rate acquisition, measurements with the electrodes at different positions in the chest area were carried out and compared. The main goal of the tests was to obtain the clearest acquisition of the QRS complex present on the ECG wave with the purpose of amplifying and filtering the peak and more accurately calculate the user's heart rate. It was concluded that the best position was below the pectoral muscles, where the electrodes are closer to the ribs, avoiding electromyography interference (Figure 1a).

Regarding the moisture sensor, as shown in Figure 1b, the best solution for the placement of the conductive bars is on the lower back, near the lumbar curvature. This is the preferred location for human's eccrine sweat accumulation, making the design less vulnerable to false positives or negatives.

Conductive leads and conductive paths were also knitted in the shirt structure to avoid electrical wires. Snap fasteners, applied to the leads allow the easy attachment of the hardware, taking advantage of the electrical conductivity of the snaps and its mechanical stability.



a) b)

Figure 1. Smart Shirt Sensor Positioning: (a) front view (b) rear view.

III. SIGNAL CONDITIONING HARDWARE

A. Heart Rate Signal

To implement the heart rate measurement conditioning hardware, the AD8232 by Analog Devices was used. The AD8232, is a single-lead, heart rate monitor front end designed to measure small biopotencial signals in the presence of noisy conditions. This front-end can be used in several configurations, being the two-electrode measurement one of them. An evaluation board was used for the tests and set for two-electrode measurement combined with low and high-pass filtering, as shown in Figure 2.

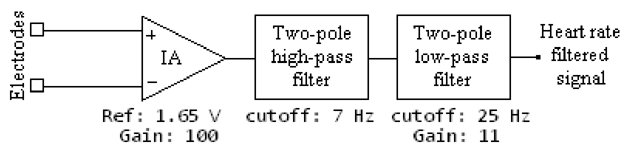


Figure 2. AD8232-EVALZ conditioning signal diagram.

In the tested configuration, the Instrumentation Amplifier has a fixed gain of 100 whilst the two-pole low pass filter adds another 11 of gain, resulting in an overall gain of 1100 V/V. Regarding the cutoff frequencies, Figure 3, the implemented block of the two-pole high-pass filter eliminates motion artifacts and drift caused by varying electrode-skin polarization and contact noise whilst the additional two-pole low-pass, using a Sallen-Key configuration, attenuates the line noise and other interference. Also, in this two-electrode configuration, the Right Led Drive (RLD) is used to drive the bias current resistors on the two electrode inputs, eliminating the third electrode needed.

In addition, the AD8232 also offers two outputs called Leads Off Detection (LOD) + and -, one for each electrode, detecting when an electrode is disconnected by sourcing a small 100 kHz current into them. When an electrode has lost its connection the accordingly LOD pin goes to a high state.

To compute the heart rate value, a CC2530 microcontroller, manufactured by Texas Instruments is used. This 2.4-Ghz IEEE 802.15.4 and ZigBee applications System-on-Chip solution is used in the project to implement the nodes of the Body Area Network in the firefighter PPE. The analysis and discussion of the wireless communication network structure will be presented elsewhere.

Using its ultralow-power internal analog comparator, with a supply current of 230 nA, it is possible to compare the filtered ECG wave with an external voltage level, as depicted in Figure 4, where the Input/Output (I/O) pins P0_5 and P0_4 correspond, accordingly, to the positive input and negative input of the comparator.

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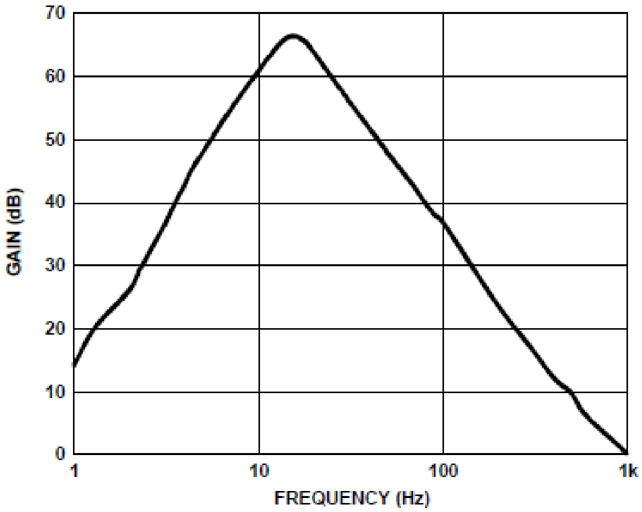

Figure 3. Overall frequency response of the heart rate signal measurement circuit.

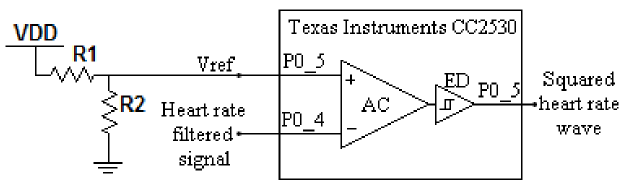

Figure 4. TI CC2530 – Analog Comparator block diagram and external components.

The voltage reference is set by a fixed voltage given by an external voltage divider and the output is internally connected to the I/O controller interrupt detector and can be treated by the Microcontroller Unit (MCU) as a regular I/O pin interrupt, being possible to configure the edge detection of the interrupt as rising or falling edge. This whole analog comparator solution compares the voltage reference with the ECG signal and when the ECG signal drops below the voltage divider value, set to 300 mV, the comparator output gives a logical one, triggering the masked Interrupt Service Routine (ISR) for port 0.

To calculate the user's heart rate value, a timer of the CC2530 is used to measure the time between two heart rate pulses. After fifteen triggers the average of these values is used to compute the heart rate.

B. *Moisture Sensor*

The physical principle of the textile moisture sensor is based on the variation of the electrical resistance of a non-conductive textile material when moisture, promoted by sweating, is absorbed or dispersed. The moisture sensor consists of two pads of conductive knitted fabric, which are used as terminals for measurement of the electrical resistance, separated by a non-conductive knit base-fabric.

For the signal conditioning of the moisture sensor, the approach represented in Figure 5 was adopted.

With this signal conditioning technique, it is possible to adjust the sensitivity of the moisture measurement by adjusting the input voltage E. Furthermore, a linear relationship between output voltage and sensor resistance is obtained [19].

Measurements are taken using the microcontroller's internal Analog-to-Digital Converter (ADC).

IV. RESULTS AND DISCUSSION

A. *Shirt prototype*

Using the knitting machine's structure design software, the leads and the moisture sensing area pads were designed and integrated in the shirt as described above. Figures 6 and Figure 7 show the front and rear view of the finished prototype.

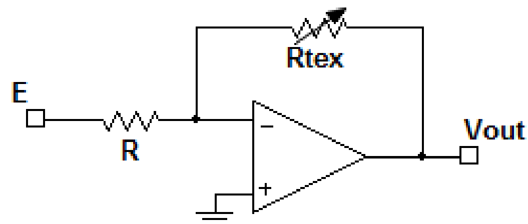

Figure 5. Inverting operational amplifier approach.

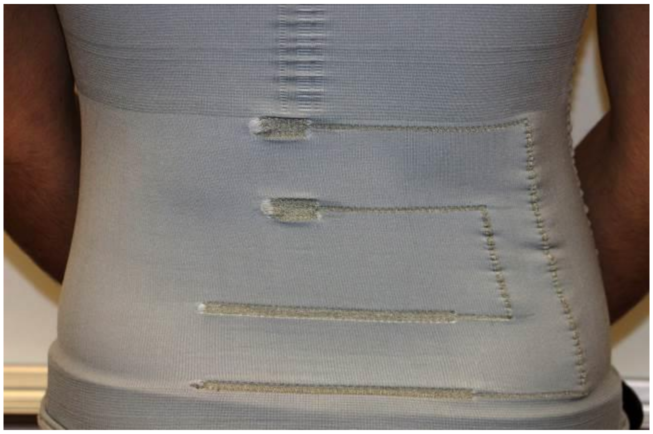

Figure 6. Shirt rear view with moisture sensor.

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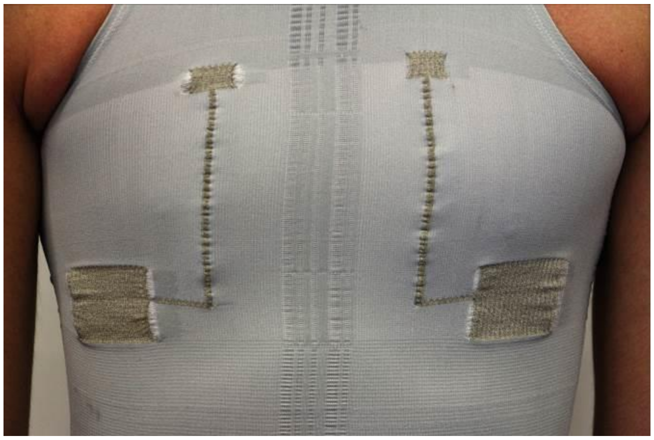

Figure 7. Shirt front view with ECG electrodes.

B. *Heart Rate signals*

Heart rate signals were acquired in different user's posture and movement conditions using a National Instruments (NI) NI-USB-6211 data acquisition device and NI Labview Signal Express software.

The signals depicted in Figure 8 were obtained with the user standing still. The waveforms represented are the output of the high-pass filtered AD8232's Instrumentation Amplifier (blue) and the amplified and low-pass filtered output signal. A clear and constant excursion of the signal from the 1.6 V dc level of the signal to nearly 0 V is observed. Analog comparison with the 300 mV threshold used at the microcontroller's analog comparator delivers the heart rate pulses very robustly. In the conditions and location of the experiment – the research lab in which the project is being developed – line and other noise are very small when compared to the relevant signal's amplitude. In future experiments, noise interference will be studied in more detail.

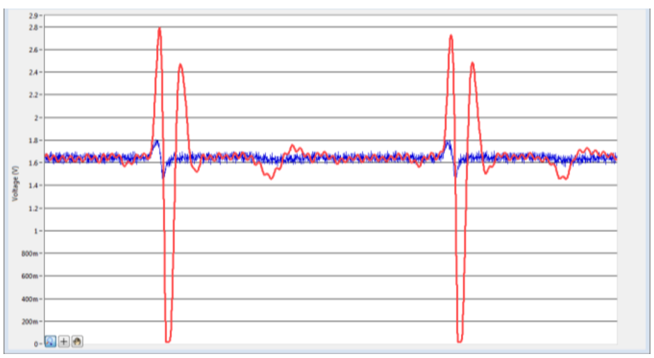

Figure 8. IA output (blue) and ECG filtered and amplified wave (red).

As soon as movement is added, the signal presents increasing motion artifacts, as well as missed heart beat pulses due to momentary loss of contact of the electrodes with the skin. The signal presented in Figure 9 was acquired with the user swinging and flexing the arms vigorously, whilst the signal depicted in Figure 10 results from an intense whole-body movement, with the user jumping and moving the arms. In both situations, some heart rate pulses are missing and in the second situation the motion artifacts produce the detection of false positives. It can also be observed that no problem due to dc level drift is present.

To compare these results with established, commercial products, a Polar model T-34 heart rate chest strap and receiver was also used in the experiments. Figure 11 shows the signal obtained with the user moving the arms vigorously.

As can be observed, the Polar heart rate monitor also misses heart beats. With intense full-body movement, false positives have also been observed. From the experiments it was clear that the two systems behave similarly in terms of heart rate measurement, failing information under extreme activity measurement conditions.

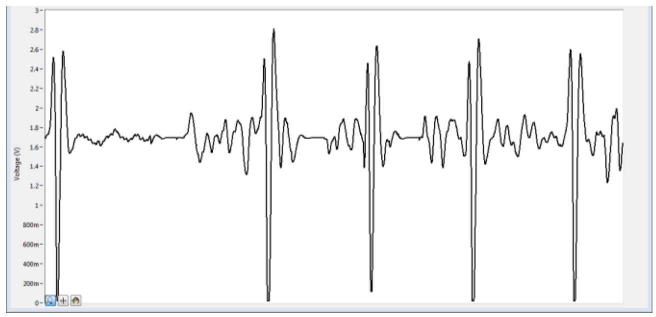

Figure 9. Arms moving vigorously while acquiring heart rate signal.

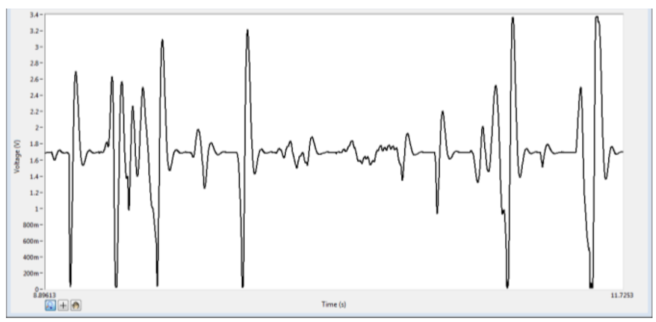

Figure 10. Intense movement of the body while acquiring heart rate signal.

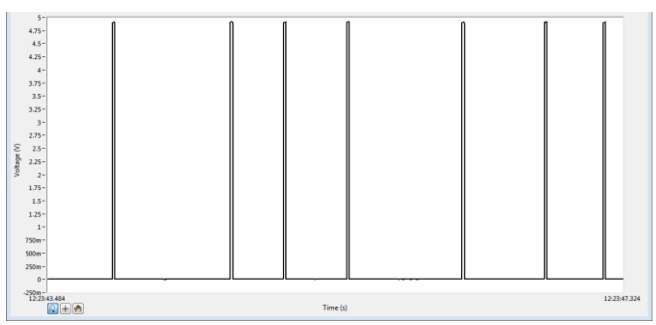

Figure 11. Polar T-34 heart rate response while vigorously moving the arms.

However, it has to be stressed that in normal running movement, measurement errors are insignificant with both systems.

C. Moisture sensor

The moisture sensor integrated in the shirt, shown in Figure 6, was previously studied using test samples such as the one represented in Figure 12. These preliminary tests were carried out to assess the behavior of knitted moisture sensors with moisture content and were performed in a chamber with controlled temperature. The samples were kept at a constant extension, to simulate wearing conditions, and a graduated syringe connected to a spray dispenser allowed to apply controlled quantities of artificial acid and basic sweat solutions. Resistance was logged with a precision multimeter throughout the experiment.

The sample represented in Figure 12 was produced with 100% cotton yarn, 30 Ne, in the non-conductive part of the knitted fabric, and Elitex multifilament polyamide silver coated yarn, 235 dtex, in the conductive part.

The results obtained in resistance change with the samples containing different amounts of acid and basic sweat solutions are represented in Figure 13 and Figure 14.

The graphs show that resistance is an order of magnitude higher with the acid sweat solution. On the other hand, with the basic sweat solution, resistance values tend to saturation with smaller quantities of sweat. In both cases the quick change of resistance makes it clear to distinguish between a dry and a wetted state of the sensor.

Figure 12. Sample for preliminary moisture sensor test.

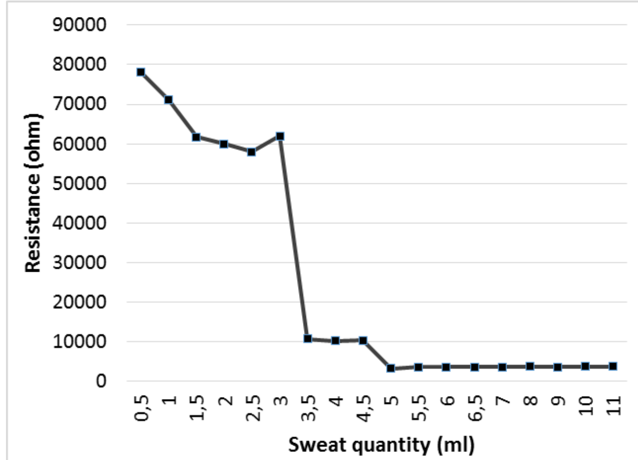

Figure 13. Resistance change with sweat quantity, acid sweat solution.

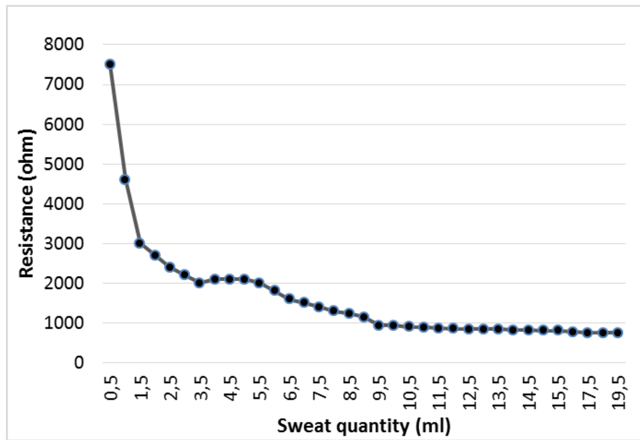

Figure 14. Resistance change with sweat quantity, basic sweat solution.

Based on these preliminary results, it is apparent that further testing is required. The influence of the sensor's geometrical parameters and non-conductive yarn material on the sensor's saturation behavior will be studied. A field trial will also be performed, to determine how the saturation point of the sensor matches the detection of the moisture content that may produce danger to the user if exposed to high temperatures.

V. CONCLUSIONS AND FUTURE WORK

This paper presents an overview of a smart shirt, where the dependence on non-textile materials to achieve interactivity is minimized. The performance of the textile sensors for heart rate measurement has been found to be comparable to the one of commercial products. Further experimentation is needed to define the final configuration of the moisture sensor.

The final design of the smart shirt will take into account other factors such as aesthetics, comfort, connection and support of hardware, electrical isolation in at some key points. Two battery-powered hardware modules, one for

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each sensor, inside a custom 3D-printed case will be attached to snap fasteners applied to the conductive leads. The snaps will assure both mechanical retention, as well as electrical connection. The modules will be integrated in a Body Area Network (BAN), to which other nodes will be connected to monitor other variables or provide information to the user of the firefighter PPE.

ACKNOWLEDGMENT

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User Privacy in Health Monitoring Wearables

Requirements stemming from current and proposed European Union legislation

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***Abstract*—Health monitoring wearables are a new type of mobile devices that are worn on the user's body and are becoming a huge trend. These devices (and the respective software needed to run the services) can track data like heartbeat and blood oxygen level, which are rightfully considered as sensitive data. If these data fall into the wrong hands, this could have serious consequences. To what extent do the five selected wearables comply with current and proposed EU data protection legislation and (how) can the privacy policies be improved? The EU is currently negotiating a new data protection regulation that will replace the Data Protection Directive. Therefore, the focus will be on the new General Data Protection Regulation (GDPR). It turns out that most market players in the field of health monitoring wearables are not ready for the coming into force of the GDPR. This paper proposes a number of improvements to better prepare data controllers for the upcoming regulation and strengthen the privacy rights of consumers.**

Keywords: health monitoring wearables; user privacy; EU legislation; compliance with legislation; data protection.

I. INTRODUCTION

Wearable technology is getting more and more implemented in our daily lives. This innovation can alter the landscape of society and business as we know it [1]. For example, the use of wearable technology in employer-sponsored health programs can lead to a healthier and more productive workforce. However, there is also a downside, using health monitoring wearables can lead to privacy risks because of the privacy-sensitive nature of the data that the applications track. When third parties, such as future employers or insurance companies have access to this sensitive data, they can adapt their agreements and policies to the specific person, not always in the advantage of the wearable user.

A. *Health monitoring wearables*

Health monitoring wearables track activity-related data such as steps taken, distance and calories burnt and are expected to help people achieve a (more) healthy lifestyle. The Misfit Shine [2], TomTom Runner Cardio [3], Samsung Gear Fit [4], Medisana ViFit Connect [5] and the Withings Pulse Ox [6] are analysed. The devices have been selected by the Tilburg Institute for Law, Technology, and Society to represent the diversity in the available wearables. The devices have their own smartphone and/or desktop app and some even share data with other weight loss or fitness apps.

All apps track steps and distance travelled, calories burnt and sleeping time. The Withings Pulse Ox also measures the user's heart rate, blood oxygen level and tracks sleeping cycles. Samsung Gear Fit can also measure the user's heart rate and can show incoming notifications on its screen (see Figure 1).

	Steps	Distance	Calories	Speed	Elevation climbed	GPS tracker	Sleeping time	Sleeping cycles	Heart rate	Blood oxygen level	Messages & calls	Agenda
Misfit Shine	✓	✓	✓	X	X	X	✓	X	X	X	X	X
Samsung Gear Fit	✓	✓	✓	X	X	X	✓	X	✓	X	✓	✓
Withings Pulse	✓	✓	✓	X	✓	X	✓	✓	✓	✓	X	X
TomTom Runner Cardio	✓	✓	✓	✓	X	✓	X	X	X	X	X	X
Medisana ViFit Connect	✓	✓	✓	X	X	X	✓	X	X	X	X	X

Figure 1. Functionalities of selected wearables.

B. *Legal perspective*

From a legal perspective, the predominant legal basis for processing personal data collected by the analysed wearables, is consent. Users are expected to agree with terms and conditions that they may not have read, let alone have understood, ultimately resulting in a lack of the elements of a valid consent.

This paper discusses the obligations of controllers and processors of personal data and conducts an assessment for compliance with existing and proposed legislation in this

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field, with an emphasis on the latter. The current EU legislation that applies to the processing of personal data, is the Data Protection Directive (DPD) [7] along with a few other legal acts, such as the E-Privacy Directive [8]. The EU is currently negotiating new data protection laws. It is foreseen to replace the DPD with a regulation, a legislative instrument directly binding upon all EU member states.

The General Data Protection Regulation (GDPR) [9] will likely come into force in 2018 [10]. One of the novelties that the GDPR brings is a set of six graphical forms, each representing a different requirement that data processors must use to comply with information obligations laid down in the GDPR. Each of them should be accompanied by either a checkmark on green background, representing compliance, or a cross on red background, standing for non-compliance.

The analysis includes both the devices as such and the corresponding privacy policies of the services listed in [2] until and including [6]. For the sake of conciseness, the service providers are referred to with their popular commercial names (e.g., Samsung instead of Samsung Electronics (UK) Limited). Citations used as examples have been taken from the above listed privacy policies.

C. Structure

Section 2 of the paper will describe important definitions, the obligations lying on the controllers and will also focus on the differences between the current and proposed regulation. Section 3 will compare the privacy policies of the wearables with the current and new regulation to assess if they are compliant and proposes a number of improvements. A table containing the graphical forms will be presented in the same section as an example of a correct implementation of the standardised information policies in practice. The paper will end with a conclusion in Section 4.

II. CONCEPTS OF DATA PROTECTION LEGISLATION AND THE CHANGES THE GDPR WILL BRING

On January 25, 2012 a proposal for a data protection regulation was released. The GDPR will be directly applicable in all member states. The proposal aims at high data protection standards, which are better harmonised and fit for the internet age [11]. On March 12, 2014 the European Commission adopted the text with amendments (in first reading) [12]. The Parliament voted overwhelmingly in favour of the GDPR [13] and now it is up to the Council of Ministers to review the Regulation. This paragraph analyses the most important concepts of data protection regulation and the changes of the GDPR with regard to them.

A. Users of personal data

The users of personal data can either be controllers, processors, third parties or recipients. The distinction between these legal concepts is important because it determines who shall be responsible for compliance with the data protection rules, how data subjects can exercise their rights and what the applicable national law is. The definitions of users of personal data will likely remain the same under the GDPR.

A controller is “a natural or legal person, public authority, agency or any other body which alone or jointly with others determines the purposes and means of the processing of personal data” (art. 4(5) GDPR). All of the researched service providers can be qualified as controllers. A processor is “a natural or legal person, public authority, agency or any other body which processes personal data on behalf of the controller” (art. 4(6) GDPR). A third party is someone who is legally different from the data subject, controller or processor. Recipient is a broader term, the definition of which is someone to whom data are disclosed (art. 4(7) and 7(a) GDPR).

B. Personal data

Personal data is defined in the DPD as “any information relating to an identified or identifiable natural person”. An identifiable person is “one who can be identified, directly or indirectly, in particular by reference to an identification number or to one or more factors specific to his physical, physiological, mental, economic, cultural or social identity” (art. 2(a) DPD). The GDPR broadens the definition of personal data by including more examples of identifiers.

C. Sensitive (health) data

Sensitive data, as a subcategory of personal data, includes health data. In contrary to the DPD, a definition of health data is given in the GDPR, namely “Data concerning health means any information which relates to the physical or mental health of an individual, or to the provision of health services to the individual” (art. 4(12) GDPR).

D. Data processing

Data processing is defined as “operation or set of operations which is performed upon personal data, whether or not by automated means”, under art. 2(b) DPD. Slight changes have been made in the GDPR that do not affect the scope of the notion that this term covers.

E. Consent

Data processing is only allowed on the basis of a legal ground, listed in art. 7 DPD. Because wearables can collect sensitive data, the only remaining legal basis for legitimate data processing is consent (art. 8 DPD).

One of the major changes of the GDPR is the concept of consent. If no other legal ground is applicable, data subjects have to give their explicit consent for the processing and storing of personal data (art. 4(8) GDPR). Explicit consent is needed not only for sensitive personal data but for all personal data. The GDPR will require consent to be expressed by a statement or by a clear affirmative action. So, explicit consent will be given when data subjects sign a consent form that clearly outlines the purposes for which the

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data is collected and processed. This could include ticking a box when visiting an internet website [14].

F. Quality principles

There are five main groups of principles relating to data quality. The qualities are set forth in art. 6(1)(a-e) DPD: lawfulness and fairness, purpose limitation, data minimisation, accuracy and storage minimisation. Art. 5 GDPR restates the five quality principles from the DPD with a few amendments. The principles of data minimisation, storage minimisation and purpose limitation are included in the standardised information policies as set out in art. 13a(1) GDPR. Each of these principles has its own corresponding pictogram which is part of the Annex to the Regulation named 'Presentation of the particulars referred to in article 13a'. The Annex explicitly states that compliance with these three requirements is "required by EU law".

III. Conducting an Assessment of Controllers' Privacy Policies Compliance With Statutory Obligations

The compliance assessment proved to be difficult to conduct because the privacy policies of the analysed wearables use vague expressions, lack details and do not address all the statutory requirements specifically. This mainly holds for storage minimisation and purpose limitation. Moreover, most of the policies do not address data retention and encryption.

This section points out the requirements the controllers do not comply with. Recommendations are made with regard to how these examples of non-compliance can be tackled. Emphasis is being put on the requirements as prescribed by the latest draft of the GDPR.

A. Data minimisation

All of the services have been estimated not to collect an excessive amount of personal data, thus being overall compliant with the data minimisation principle (see Figure 1), as laid down in art. 6(1)(c) DPD and art. 5(1)(c) GDPR. None of the privacy policies provide an exhaustive list of all the types of data collected and retained. However, collection of data such as the exact date of birth of the user required by Withings and Samsung might be considered excessive.

Firstly, because proving that the user is not a minor can be achieved through other means and secondly because just the year of birth would not unreasonably limit the functionalities of the services. Offering the option to use a non-identifying nickname instead of requiring the full name of the user, an approach used by Medisana, is another practical suggestion to promote the principle of data minimisation.

The GDPR pays extra attention to the principle in question by adding the requirement that "[data] shall only be processed if, and as long as, the purposes could not be fulfilled by processing information that does not involve personal data".

B. Purpose limitation

The service providers have given examples of the purposes for which data are collected, but the lists do not appear to be exhaustive so as to unambiguously comply with the purpose limitation requirement. This is laid down in art. 6(1)(b) DPD and art. 5(1)(b) GDPR and requires controllers to be specific and explicit with regard to data processing purposes.

Concerning the element of the same requirement that prescribes that data shall not be further processed in a way incompatible with purposes rather than the ones for which they were initially collected, all of the assessed service providers' privacy policies seem to be compliant (see Figure 2). However, this conclusion has been made solely on the basis that none of the service providers has hinted such a scenario. To avoid any confusion and to demonstrate responsibility, the service providers need to list all of the purposes for which the personal data are collected. Furthermore, they also need to state explicitly and clearly that they will not further process the collected personal data in a way incompatible with the initial purposes without the acquisition of a separate consent.

C. Access to data by third parties

None of the privacy policies explicitly mention that the collected personal data might be sold or rented out. Out of the five assessed policies only the Samsung privacy policy gives a clear example of disseminating personal data to commercial third parties. Even though the latter might be considered to be overlapping to a certain extent with the former, both are separate requisites under the GDPR. Samsung's privacy policy states that "[Samsung Electronics (UK) Limited] also may share your information with trusted business partners (…) [who] may provide you with promotional materials, advertisements and other materials".

While the service providers are not forbidden to share collected personal data with third parties in general, they still have to unambiguously indicate their conduct regarding the sharing of data. The approach undertaken by the controllers, with a single exception, namely not to explicitly address these requisites, leads to the lack of information for the users with regard to compliance with art. 13a(1)(d) and (e) GDPR (see Figure 2 for both requisites). A general recommendation to address this issue therefore is that all the controllers should clearly state if personal data are disseminated, whether or not by subcontractors, to commercial third parties. The same approach should also be applied to whether personal data are sold or rented out.

D. Storage minimisation and data retention

Art. 14(1)(c) of the GDPR introduces the requirement that either the period for which the personal data will be stored should be specified, or if this is not possible, at least the criteria used to determine this period should be

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described. Only Samsung's privacy policy addresses this requirement by stating that information about the data subjects will be kept "only for so long as is necessary for the purpose for which it was collected". This wording is, however, too vague and not definite enough to fulfil the statutory requirement. Therefore, none of the controllers fully complies with this requirement (see Figure 2). Different types of data may be stored for different periods. A user-friendly approach to incorporate such a list in the privacy policy of a service would be to make use of multi-layered notices, as suggested by the Article 29 Working Party [15]. Such an approach can be a useful solution also for the listing of the types of data collected and the purposes for which they are going to be used.

After the purposes for which the user data were collected have been fulfilled these data should be erased. Otherwise, they should be anonymised or pseudonymised. These requirements are set out by art. 6(1)(e) DPD and art. 5(1)(e) GDPR. The process of anonymisation or pseudonymisation should, when possible, be already implemented in the stage of collecting data. This should only be the case when it will not lead to limitations of the functionality of the service.

E. Encryption

While encryption is voluntary under the GDPR, pursuant to art. 13a(1)(f) of this Regulation the service providers should still state whether personal data are retained in encrypted form. Only one of the assessed controllers complies with this requirement of the GDPR (see Figure 2). The requirement itself can be considered restrictive in naming a single amongst all possible technical measures to protect privacy. To fulfil this requirement the service providers should mention encryption explicitly. This does not mean that all other possible organisational and technical security measures should not be mentioned in the privacy policies, as the requirement for implementing such measures is prescribed by art. 17(1) DPD and art. 26(1) GDPR.

F. Information about the controller and processor

Pursuant to the requirements of art. 10(a) DPD and art. 14(1)(a) GDPR the controller must provide the data subjects with information about itself and its representatives, if any. In other words, the service providers, along with information about themselves, should also provide information about subcontractors or processors of user data. In case they do, the privacy policies should include the identity and the location of the processors and a description of the processing activities.

Samsung, for instance, in its privacy policy gives explicit examples of its affiliates and mentions that information may be passed on to sub-processors referred to as "service providers", whereas Medisana provides in its privacy policy the most information about the legal entity that serves as a controller. However, none of the assessed controllers gives enough information to fulfil all aspects of this requirement to a sufficient extent.

G. Data storage

The service providers should list the locations of all the servers where users' data are stored. The location should be specific enough, especially if the data are stored on a server located outside the European Economic Area (EEA). In the latter case, according to art. 26(1)(a) DPD and art. 44(1)(a) of the GDPR, the service providers should also point out which security and data protection standards does the server in question comply to. Out of the assessed service providers the best approach has been undertaken by TomTom by being clear and thorough enough in stating in its privacy policy that "TomTom and [their] partners and subcontractors have taken adequate security measures to protect [users'] information from unauthorized access. Some of these partners and subcontractors are located outside the EU. [They] have contractually bound them to provide a level of protection of [users'] data according to European data protection legislation and they take full responsibility and accountability for this". Still, this description lacks a list, exhaustive or not, of countries where data may be stored. Misfit, for instance, in its privacy policy provides a single example by stating that data may be transferred "globally, including to the United States".

H. Right of access to data

The users have the right to obtain from the service providers at any time, on request, confirmation as to whether or not personal data related to them are being processed, as well as detailed information on the processing activities. The description should be in clear and plain language pursuant to the requirement of art. 12(a) DPD and art. 15(1) GDPR. Furthermore, according to art. 12(b) DPD as well as art. 14(1)(d) and 17(1)(b) GDPR the users should also be provided with a procedure to rectify, erase or block their data on a number of grounds.

Most of the assessed service providers comply with these requirements. However, Samsung's privacy policy mentions that the service provider "may charge a reasonable fee for dealing with [access to data] request" and Withings requires in its privacy policy a "request by post to the address of Withings' registered office". Both approaches are undesirable for an Internet-based service. Misfit's privacy policy states that this service provider "currently [does] not have a way to let [the users] correct or update [their] personal information", thus explicitly declaring non-compliance with the rights in question.

IV. CONCLUSION

This paper examines a number of requirements under existing and new data protection legislation that might pose privacy and data protection risks for users of health wearables. This list is, however, not exhaustive, i.e., it does not address all obligations lying on data controllers.

To conclude, the selected controllers are not fully ready for the adoption of the GDPR and also do not fully comply with most of the current requirements under the DPD.

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Compliance with the new requirements under the GDPR is advisable as it will provide a smooth transition for both controllers and users of the wearables by the time the new regulation comes into force. Non-compliance with the current legislation is, however, a serious issue that needs to be taken care of without delay.

To achieve this, every statutory requirement should be explicitly addressed in clear and plain language. The privacy policies are the only source of information for (prospective) users of the wearables. This is why compliance with a requirement in practice is not enough, stating it in writing is as important.

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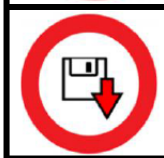
	EXPLANATION	MISFIT SHINE	TOMTOM RUNNER CARDIO	SAMSUNG GEAR FIT	WITHINGS PULSE OX	MEDISANA VIFIT CONNECT
	No personal data are collected beyond the minimum necessary for each specific purpose of the processing	✓	✓	✓	✓	✓
	No personal data are retained beyond the minimum necessary for each specific purpose of the processing	X	X	X	X	X
	No personal data are processed for purposes other than the purposes for which they were collected	✓	✓	✓	✓	✓
	No personal data are disseminated to commercial third parties	✓	✓	X	✓	✓
	No personal data are sold or rented out	✓	✓	✓	✓	✓
	No personal data are retained in unencrypted form	✓	X	X	X	X

Figure 2. Compliance chart.

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Intelligent Wireless Body Area Network System for Human Motion Analysis

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***Abstract*— Human motion analysis provides several important applications. Examples are fall risk assessment, sports biomechanics, physical activity monitoring and rehabilitation. This work in progress paper proposes an intelligent wireless body area network system for motion and gait symmetry analysis. A Bluetooth network with accelerometers, gyroscopes and in-shoe force sensing resistors gathers data and sends it to a web server after intelligent pre-processing and filtering. The system is flexible and adaptable for different use cases including combinations of gait analysis, gait symmetry and pressure measurements between foot and shoe.**

Keywords*— *motion analysis; wireless; body area network; Bluetooth Low Energy.

I. INTRODUCTION

Analysis of human motion provides several important applications. One example is fall risk assessment in the ageing population. Falling accidents are common and the frequency increases with age and often result in injury or even death [1]. The falls are also a cost for the individual as well as for the society. Other motion analysis applications are rehabilitation [2][3], sports activity monitoring [4] and evaluation of the amount of physical activity in daily life [5]. Gait symmetry analysis is an important form of motion analysis [6].

Portable motion analysis can be done in several ways and some of the more popular choices of sensors include accelerometers, gyroscopes and in-shoe force sensing resistors. A combination of these approaches would give a more complete motion analysis.

Pedobarography, the study of pressure fields acting between the plantar surface of the foot and a supporting surface, have been used in gait and posture analysis [7] but also in prosthetics evaluation [8] and sports biomechanics[9]. Accelerometers are common for monitoring physical activity and can measure the position and motion of the body together with gyroscopes [10].

The two most popular pedobarography measurement systems that offers telemetry options are Novel's Pedar. (Novel GmbH, Munich, Germany) with capacitive sensors and Tekscan's F-Scan (Tekscan Inc., Boston, MA, USA) with resistive sensors.

These systems cost over €13000 for the wireless versions. F-scan measures up to 0.86MPa and is 0.15mm thick. Pedar measures up to 1.2MPa and is 1.9mm thick.

A commercial system with inertial measurement units is SHIMMER3 (Shimmer, Dublin, Ireland). It is equipped with a MSP430 (Texas Instruments Inc., Dallas, TX, USA) microcontroller unit and uses Bluetooth 2.0 to communicate with other units.

This paper describes a wireless system for motion, gait and symmetry analysis. A body area network with accelerometers, gyroscopes and in-shoe force sensors is proposed. The amount of sensors is decided by each application. Bluetooth low energy chips are used for the local data communication. Data can be stored locally in a data sink until communication with a web server is available. Calculations and analysis with low computational burden will be done in the sensor nodes and in the data sink to save bandwidth.

The proposed system is described in Section II, with four subsections for (A) hardware, (B) data communication, (C) analysis and (D) initial measurements. Discussion will be in Section III.

II. SYSTEM DESCRIPTION

A wireless body sensor network with up to seven motion processing units, eight force sensing resistors and two temperature sensors is proposed. A data sink is used for temporary local data storage and uses mobile telecommunication or Wi-Fi to connect to a web server.

A comparison of the proposed system and other similar systems are shown in Table 1. The other systems are called Physilog 4 Silver (Gait Up A.S., Lausanne, Switzerland) [11], GaitShoe [12] and SmartStep [13].

A. Hardware

Bluetooth Smart modules BLE113 (Bluegiga Technologies Ltd., Espoo, Finland) provides wireless communication between up to seven sensor nodes and the data sink. BLE113 has an 8051 microcontroller and an 8 channels 12-bit analog-to-digital converter (ADC) at 4kHz for connecting external sensors such as the force sensing resistors.

Table 1. COMPARISON BETWEEN THE PROPOSED SYSTEM AND SIMILAR SYSTEMS

Name	**Node dimensions [mm]**	**Node weight [grams]**	**Sensor types and analog-to-digital resolution [bit]**	**Data communication**	**Sampling frequency [Hz]**	**Battery life time [hours]**
Proposed system	41x34x15	Slightly over 20g	3D accelerometer (16-bit) 3D gyroscope (16-bit) 3D magnetometer (13-bit) Force sensing resistors (12-bit)	Bluetooth Low Energy ver. 4.0, 3G/4G or Wi-Fi to send data to server	At least 1kHz is possible, 30Hz currently until programming is improved	Weeks without the force sensing resistors, otherwise at least 24 hours
Physilog 4 Silver (Gait Up, newer version than in the article) [11]	50x37x9.2	19g	3D accelerometer (16-bit) 3D gyroscope (16-bit) 3D magnetometer (13-bit) Barometer	RF node sync., local data storage, cable to transfer data to computer	Up to 500 Hz	Up to 21 hours
GaitShoe [12]	25x44x17	Less than 22g	3D accelerometer 3D gyroscope Force sensing resistors Electrical field sensor Bend sensor (12-bit)	RF	75Hz	6 hours
SmartStep [13]	Not known, node located on back of shoe	Total system weight is less than 35g	3D accelerometer Force sensing resistors (12-bit)	RF	25Hz	20 hours

Each sensor node has a 9 degrees of freedom motion processing unit MPU-9150 (InvenSense Inc., Sunnyvale, CA, USA). It has a 3-axis 16-bit accelerometer up to 1kHz, a 3-axis 16-bit gyroscope up to 8kHz and a 3-axis 13-bit magnetometer. The electronics are powered by a 240mAh lithium-ion polymer (LiPo) battery. A sensor node under construction is seen in Figure 1. Time between charging is in the order of weeks if no external sensors are used and if there is not a lot of retransmission of data due to an extremely harsh environment.

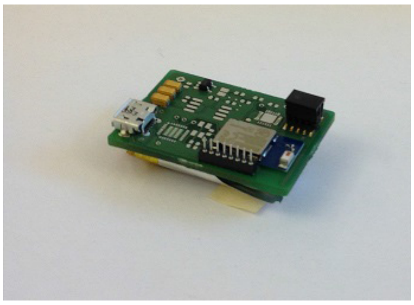

Figure 1. Sensor node prototype under construction.

Custom printed circuit boards host the following: the BLE113, motion processing unit MPU-9150, battery charging circuit with micro USB connection, JTAG interface for programming and headers for attaching an adapter card on top of the board. The block diagram of a sensor node is seen in Figure 2.

The adapter card is used with the two sensor nodes which include the force sensing resistors and temperature sensors. Amplifying circuits for these sensors are also placed on the adapter card.

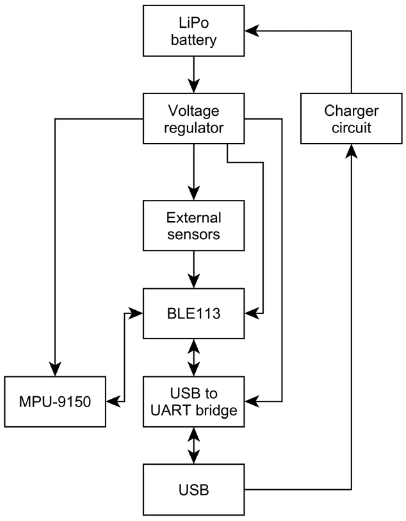

Figure 2. Sensor node block diagram.

The force sensing resistor ESS301 (Tekscan Inc., Boston, MA, USA) has a round sensing area with a diameter of 9.5mm and is 0.20mm thick. It can withstand 95% humidity and this is important because the sensors will be placed inside shoes. The temperature sensors are only used for compensation of the signal drift of the force resisting sensors due to changes in temperature. Four force sensing resistors will be used in each shoe positioned at heel (A), outer (B) and inner (C) side of the metatarsal pad and big toe (D). See Figure 3 for anatomical sensor locations. The temperature sensor goes under the foot valve and all these sensors are attached to the shoe insole which is placed inside the shoe. The discrete sensor locations are common choices decided by the bones in the foot [8][14][15].

Figure 3. A is heel, B and C are on metatarsal pad and D is big toe pad.

The chest and three nodes for each leg (at the hip, just above the knee and on top of the shoe) are the seven locations for the sensor nodes. A watertight case encloses each sensor node. The case has the dimensions 41x34x15mm and the total weight of a sensor node is slightly more than 20 grams.

B. Data communication

The seven sensor nodes and the data sink uses the eight available connections of the wireless body sensor network. An overview of the body area network is shown in Figure 4. The available bandwidth is 1.5Mbit/s in each direction. With a sampling rate of 1kHz there is still enough bandwidth left for retransmissions and overhead for time synchronization. To get reliable data, the time between all measurements needs to be known and as exact as possible. This means the system will have a reliable time synchronization protocol implemented. An example of such a network with low latency has been provided in an earlier work [16].

The BLE113 integrates Bluetooth radio with Smart stack and profiles. BLE stands for Bluetooth Low Energy and Bluetooth Smart is the marketing name. A low standby power and fast wake up is the reason for power saving compared to earlier Bluetooth versions. The standby power is always present and is one of the bigger parts of the total energy consumption together with for example the number of active connections [17]. The transmitting power will be adjusted to be just enough for the body network range to reduce possible interference.

Mobile telecommunication or Wi-Fi will link the data sink to a web server. Depending on the choice of wireless communication, a BLE compatible Android smartphone or myRIO (National Instruments Co., Austin, TX, USA) are suggested as data sinks.

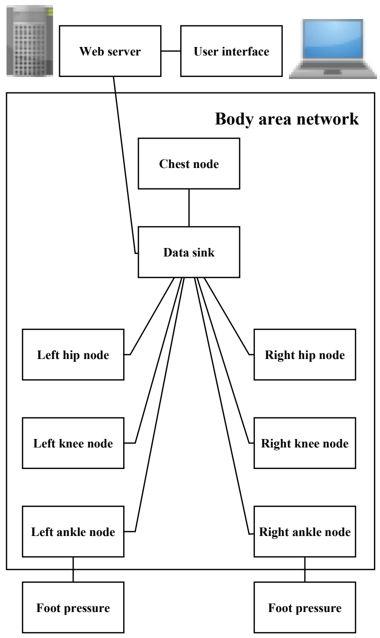

Figure 4. Body area network with 7 sensor nodes and a data sink.

C. Analysis

The main goal for the system is to check for differences in movement symmetry, so by matching periods, force and rotational velocity etc. of left and right legs it is possible to check for variance and abnormalities in this data. Interesting parameters to measure are: extremity movement symmetries, step length, velocity, peak force and the shift speed of the center of pressure.

Kalman filtration will be performed on the data gathered from the sensor nodes to remove noise and increase accuracy for the orientation data [18]. This leads to the possibility of performing better analyses of the gait symmetry. The filtrated and analyzed data will then be displayed to the user through a graphical user interface in a way that makes it easier to understand the results. There are also plans to include direct feedback options with an audio signal or vibration in the node.

D. Initial measurements

Initial measurements with the 3-axis 16-bit accelerometer and 3-axis 16-bit gyroscope have been made at 30 Hz using BGScript version 4.0 (Bluegiga Technologies Ltd., Espoo, Finland). Switching to C-programming in IAR Embedded Workbench for 8051 IDE version 8.30.3 (IAR Systems Group AB, Uppsala, Sweden) should enable a considerable increase of the sampling frequency, up to at least 1kHz.

III. DISCUSSION

In this paper, a wireless system for motion, gait and symmetry analysis has been described. A body area network with inertial measurement units and in-shoe pressure sensors is proposed.

By integrating both inertial sensors measurements and foot pressure measurements in an intelligent body area network will allow for a more adaptable and flexible system. A benefit of the system is thus that it is adjustable for various users and use cases. The number of sensors is decided by each application and the amount of transmitted data will also be adjusted for each application.

By checking for asymmetry in movement of left and right leg the system can be useful in for example fall prevention, rehabilitation, sports performance and monitoring of the amount of physical activity.

The aim was to develop a motion analysis system that could be used wherever and will not need anything else than a smartphone or PC as user interface. Depending on the application, some of the calculations can be made in the sensor nodes and the rest on the server.

Another design consideration would be to use slower sampling rates but more sensor nodes to be able to monitor the arms as well as the legs.

Technical challenges to be solved in the system are two. The first is to increasing the output rate of the motion data to 1kHz. The second is adaptable foot pressure measurements regardless of individual foot valves and shoe sizes.

However, the size and weight of the complete system is of great importance since the system must not interfere nor affect the motion itself. An even smaller and lighter sensor node format is therefore desirable.

ACKNOWLEDGMENT

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