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Impact Analysis of Solutions for Chronic Disease Prevention and Management

10th International Conference on Smart Homes and Health Telematics, ICOST 2012
Artimino, Italy, June 2012, Proceedings

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Preface

We are now living in an era where lower-cost, higher-performance technology has the potential to become truly ubiquitous as it integrates seamlessly with our everyday lives. It could be argued that the realization of these concepts will be most significant toward promoting independent living and increasing the quality of life for the rising numbers of older people and, with it, the prevalence of chronic conditions such as cardiovascular disease, cancer and dementia. Such illnesses are placing significant and unsustainable pressure on health and social care services across the globe. In an effort to help to alleviate some of these pressures, researchers are investigating the potential to embed assistive technology within home environments and beyond. Indeed, studies have shown that people with chronic illnesses often prefer to remain living within their own homes for as long as possible. A challenge in supporting their independent living is to ensure that technology-driven health solutions provide an equal quality of care when compared to institutional care facilities. Key to this success is the provision of 'smart' homes, which are able to provide automated and personalized levels of support, based on the profiles of each occupant.

Realizing a smart home is, however, not an easy task. To facilitate their successful development, smart homes are typically equipped with a large number of sensors, which are attached to household objects or embedded within appliances so that they may track the occupants. These sensors generate a large amount of data, which must then be organized and mined using computation intelligence approaches to extract features that contribute most to the recognition of particular behaviors, environmental changes or to identifying activities of daily living.

A large body of research in this area now exists; however, we have not yet witnessed the advent of truly smart homes. What is needed is a coordinated and collaborative approach to technology development based on a user-centered design methodology with strong industrial and health and social care service support to ensure large-scale uptake.

This volume contains the papers presented at the 10th International Conference on Smart Homes and Health Telematics (ICOST). ICOST is now considered as a premier venue for bringing together stakeholders from clinical, academic and industrial perspectives, along with end users and their family carers to explore how smart homes and health telematics can foster independent living and offer an enhanced quality of life. The ethos behind the conference is to promote collaborative stakeholder-led research in an effort toward realizing the true potential that smart homes and health telematics services can offer.

After nine very successful conferences held in France (2003), Singapore (2004), Canada (2005), Northern Ireland, UK (2006), Japan (2007), USA (2008), France (2009), Korea (2010) and Canada (2011), the 10th International Conference on

Smart Homes and Health Telematics was hosted for the first time in the Tuscany region of Italy, during June 13–15, 2012.

Each year, the conference focuses on a particular theme. We felt it was pertinent during the 10th anniversary of the event that the theme should be related to the “Impact Analysis of Solutions for Chronic Disease Prevention and Management.” This LNCS volume presents the dynamic program of papers, which incorporated a range of technical-, clinical- and industrial-related keynote speakers, oral and poster presentations along with demonstrations and technical exhibits. The volume focuses on reflecting on the gains made in this research domain by reporting on the research findings of real-word deployments of assistive technology within a smart home context.

Competition among the 74 original submissions to the conference was very high. Submissions from authors from over 25 countries were reviewed by an International Program Committee consisting of domain experts from over 15 counties. In the end, 25 full papers were accepted (34%) for oral presentation with a further 22 short papers accepted (30%) for poster presentation at the event. These papers were categorized into a number of sessions that include: “User Engagement for Improved Adoption of Assistive Technologies”, “Self-Management and Tele-Rehabilitation”, “Advances in Remote Monitoring and Activity Recognition”, “Sensor Networks for Unobtrusive Monitoring Solutions”, and “Real World “Aware” Systems”.

We would like to take this opportunity to sincerely thank the Scientific Committee for the guidance during the preparations for the event and especially all of the Program Committee who worked tirelessly to deliver reviews within a short time frame. Their efforts have contributed toward producing this volume, which contains an exciting and varied range of scientific studies. We thank the Organizing Committee members who devoted their time over several months to prepare for and support the delivery of the conference. We would also like to specially acknowledge the EasyChair Conference System, which facilitated the paper submissions, the review process and the proceedings generation. Finally, we wish to acknowledge all of the support received from the event promoters, which helped host the conference at such a special venue.

June 2012

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Challenges of User-Centred Research in the Development of Ambient Assisted Living Systems

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Abstract. The SOPRANO (Service-oriented programmable smart environments for Older Europeans) project was an EU-funded project to develop an ambient assisted living (AAL) system to enhance the lives of frail and disabled older people. A major aim of the project was to shift away from 'technology-push' and 'problem-focused' approaches to user-driven approaches and map out an AAL system that will provide practical benefits for users in their everyday lives. The SOPRANO project involved users at all stages in the iterative development of an AAL system. This paper presents the main findings from the study, reflects on the key challenges in adopting a user-centred approach, and identifies some of the barriers to the widespread implementation of AAL systems within the spectrum of care for older people.

Keywords: Assistive technology, user-centred research, older people, markets.

1 Introduction

Information and communication technologies (ICTs) are a potential solution to help meet the health and social care needs of an increasing number of older people within society [1,2]. The design of assistive technologies has recently advocated a shift towards user-centred research, involving older people at each stage of the research and development (R&D) lifecycle [3,4]. Grounding the R&D process in the real experiences of older people can bring about technologies that are more acceptable, ethical and supportive within everyday life [5]. In doing so, it is recognized that technology within the home needs to accurately respond to the changing routines of older people by placing them in control, not of the technology, but of their own lives [6]. Here, the focus of human computer-interaction should be on supporting the activities of older people, providing the tools to enhance choice and independent living [7]. Furthermore, devices need to be intuitive and intelligent enough to support the routines and activities of older people, incorporating the social aspects of human-computer interaction [8] and being 'context aware' by adapting to changes without being intrusive to the older person [9].

Whilst the benefits of user-centred research are clear, it can be difficult in practice, requiring flexibility in the research process, the capacity to undertake relationship-building and sensitivity to the needs of older people themselves [10]. Moreover, user-centred research takes place against a backdrop of poor take-up amongst emerging

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AAL systems, suggesting that the development of such technologies also requires an understanding of barriers to market [11]. This paper reflects on the experiences of the EU-funded SOPRANO project, highlighting the challenges in undertaking user-centred research and the difficulties in managing the expectations of older people, academics and technologists in the R&D process, whilst ensuring that the technology is shaped around the lifestyles of the end user. The paper points to the closer alignment between user-centred design and achieving a viable marketable product. Both are important if ICTs are to become part of a flexible, integrated system of care that dovetails with existing service provision [12].

2 The SOPRANO Project

SOPRANO (Service Oriented Programmable Smart Environments for Older People) (2006-11) was an EU-funded project to develop an AAL system that enables older people to live independently at home, through an unobtrusive assistive technological solution that requires the active participation of the user, thus supporting independent action. The SOPRANO system incorporated: ***sensors and alerts*** to detect breaches in safety such as leaving a door open or appliance operating; ***reminders and prompts*** to take medication and confirm upcoming appointments; and an ***intuitive user interface*** to interact directly with the older person and encourage participation in activities such as exercise and healthy eating. The project was guided by an Experience and Application Research (E&AR) to ensure participation by end-users (older people, carers and service providers) in the R&D process [13] including the requirements specification, the development of use cases, the prototyping of the SOPRANO system and the implementation and evaluation of systems within the homes of older people. The project involved a consortium of twenty enterprises, public bodies, universities and research institutes across seven European countries.

2.1 User Requirements

The user requirements of older people were captured through three specific phases of the research:

1. Literature Review and Generic Situations: A total of 11 generic situations were developed to address those issues directly affecting the independence and well-being of older people. These were established from an extensive literature review in the area of ageing which encompassed ageing-in-place, activities of daily living, independence and quality of life, existing care provision. The emphasis was on establishing the needs and priorities of older people in relation to the available literature. The generic situations were grouped within the themes of psycho-social, instrumental and medical domains of care.

2. Focus Groups and Interviews: A total number of 92 users were involved in focus groups and interviews. The aim of this phase of the research was to establish an understanding of older people's experiences in relation to the care they receive, to identify gaps in existing service provision and to highlight issues which impact on independence and quality of life when living at home. This stage of the research was designed to ground the requirements in the experiences of older people themselves, using the generic situations identified in the previous phase.

3. Workshops and Use Cases: The findings from the focus groups and interviews were used to develop a set of use cases to map the functional requirements of the SOPRANO system against the needs of older people identified in the previous stage. These included: *Medication reminding, Memory facilitating, Fall detecting, Activity monitoring* and *Exercise facilitating*. The use cases were then translated into system components through three workshops co-ordinated by the consortium of academic and technical partners.

2.2 Prototyping the SOPRANO System

The outputs from the user requirements phase of the research were used to develop and design the initial SOPRANO prototype system. The initial prototype system was then evaluated through two approaches. Firstly, theatre-based workshop provided the opportunity to visualize and explore typical scenarios which confront older people within everyday life. Secondly, animated mock-ups of the various use-cases were developed in order to facilitate feedback from older people and stakeholders. The findings from this phase were analysed by the project team and the technical partners and used to drive a second prototype design. There then followed a second prototype testing (component tests) which involved 51 older people in testing the usability of the system components within group sessions across the partner sites. The findings were implemented into a final prototype of the SOPRANO system. The main components of the final SOPRANO system were (see figure 1): Home hub connected to the SOPRANO PC; passive user activity sensors (door/window sensors, motion detectors) to detect occupancy and movement; device sensors (door bell sensor, TV usage); emergency sensors (security pendant if needed); medication dispenser connected wirelessly to the SOPRANO system; interface devices (e.g. touch screen terminal to display messages when leaving the house, TV and remote control); connection devices (wireless broadband internet access, SMS gateway).

Fig. 1. Main components of the SOPRANO system

2.3 Demonstration and Field Trials

This phase of the research aimed to test levels of usability, usefulness and acceptability of the system amongst older people, carers and other stakeholders.

1. Full functional demonstrator: Installation of the SOPRANO system in demonstration facilities in the Netherlands, UK and Spain enabled users to see how different components of the system functioned.

2. Large scale demonstrator: A limited version of the system was implemented in the homes of older people in the UK, Spain and the Netherlands, allowing the system to be installed and evaluated in the homes of older participants. This only incorporated features sufficiently robust to operate in a non-laboratory setting.

A ***total number of 166 older people*** were involved in the full functional demonstrator across the three sites. A further 26 older people participated in the large scale trial. User feedback was collected through questionnaires, interviews and focus groups.

3 Key Findings

3.1 Usability of the SOPRANO System

The usability of the SOPRANO system was influenced by *previous experience* of using technology. Those who used technology (such as mobile telephones, e-mails) more frequently in their *everyday lives* were more likely to adopt the SOPRANO system. Those that did not use technology required more one-to-one support to challenge their perceived suspicion with technology, in order to habitually use the system and realize the benefits. This tailored support requires additional capacity from the research team or local trainers. *Ease of use* was also an important predictor of usability. Those that found the use cases overly complex to navigate were unlikely to use the system, whilst those that found them too simple no longer felt engaged with the system. The complexity of the functionality needs to be tailored to the changing proficiency of the user to ensure that it remains stimulating and challenging for the older person. *Learnability* was an important determinant of levels of usability. Older people with a variety of cognitive conditions require a system that is learnable so that they do not have to refer to training manuals when navigating their way around the system. It was often frustrating for users if they could not automatically pick up the system and resume where they left off and felt a burden when needing to ask the project team or family members for assistance.

3.2 Usefulness of the SOPRANO System

While the evaluation suggested that the various functions of the system were perceived to be useful, a key outcome was the need to develop systems that accommodate variability in everyday life, while also encouraging purposeful action by the individual. The usefulness of SOPRANO was determined by the extent to which the technology could provide an *overall supportive influence* in key areas of older people's everyday life. SOPRANO was most effective when incorporated into everyday routines and activities, for example, to fit in and around shopping trips, visits from the carer, trips out with the family. The system was seen as less useful if it required significant changes to existing routines as this upset the equilibrium of the older person. Moreover, routines amongst trial participants varied significantly, negating the need for aspects of the system or requiring additional complimentality. For example, a person might go out visiting and not require the medication reminder, or required a prompt via a mobile device. This suggests that participants need increased control of the system (e.g. changing settings to avoid false alarms) and integration of the home-based system with other mobile communication platforms. Usefulness was also determined by the extent to which the system can *support and encourage* users to undertake tasks, as opposed to directly undertaking the task for them. A key advantage of the SOPRANO system was that it provided prompts which in turn required notification that those prompts had been acted upon, such as closing a window and turning off the oven as opposed to a passive monitoring system. This promoted stimulation, engagement and independent living. Long-term acceptability was also influenced by the capacity of the system to *adapt to the changing needs* of the older person. Technology is required that flexibly provides additional/less functionality as required by the user.

3.3 Acceptability of the SOPRANO System

The acceptability of the system within the home environment was controlled by a number of factors. The *role of formal and informal carers* was central to whether the older person accepted the technology. A negative reaction from informal carers lowered levels of enthusiasm amongst the older people. This demonstrated the need to involve formal and informal carers more closely in the R&D process so that they are aware of the potential benefits. Levels of acceptability were also influenced by the *perceived stigma* associated with the use of the technology. The visibility of the system within the home (by friends, family members) created a feeling amongst older people of reliance and dependency i.e. visible sign that they are vulnerable. Participants identified the importance of ensuring that the system remains 'hidden' within the home and the development of technologies should accommodate this need in their design and implementation.

4 Benefits, Challenges and Pitfalls of User-Centred approach

The research indicated that SOPRANO was successful in facilitating end-user involvement within the R&D cycle, improving usability, usefulness and acceptability of the prototype system at the demonstration phase. However, the experience within SOPRANO highlighted a number of significant challenges.

4.1 AAL in Everyday Life

Despite the effort focused on developing a system that met the needs of older users, certain aspects of usability, usefulness and acceptability remained problematic. The evaluation highlighted the challenge of how assistive technology can be seamlessly incorporated into everyday life. Perhaps the fundamental issue is the way that the "needs" of older people are conceptualized. Typically, research in this area follows a biomedical model that compartmentalizes these needs into easily managed discrete problems. This approach is likely to be more successful where the user has very specific tasks to perform, such as in self-monitoring of a health condition. The research highlighted that people want to use technologies in a flexible way according to the everyday patterns of living, which change over time as the person's capacities and goals change. This variability means that a one-size-fits-all system is likely to be discarded. The very idea of developing "solutions" to predetermined problems ignores the fact that people often make use of technologies in very creative and unanticipated ways. By their very nature these cannot be designed into a technology, but equally technologies need to be enabling rather than constraining. Overall, there is a need to move away from an agenda of dependency to an agenda of active aging. Only by blurring the boundaries between 'human' and 'computer' will AAL technology be seamlessly integrated into everyday life. Here, AAL technology needs to adhere to the 'personalisation' of technologies which are seen as an extension of the self, and better encapsulate an understanding of the identity of the older person.

4.2 Relationship-building

Working closely with users requires developing and sustaining relationships with local providers and older people to ensure that trust and reciprocity is developed between the research team and users. This relationship-building requires considerable investment in terms of time and effort, as well as the need to apply aspects of good partnership-working: two-way communication, active listening, and shared dialogue. A positive aspect of SOPRANO was the relationship developed with local providers who provided the knowledge on the ground, assisted in recruitment and sustained the enthusiasm of the trial participants. However, local providers and older people need to be suitably remunerated and their time appropriately costed into user-centred research projects from the outset. Undertaking a multi-methods approach and engaging users at each stage of product development also brings a unique set of demands for the participants. A comprehensive user-centred approach can lead to consultation fatigue, resulting in participant attrition at key stages of the research, impacting on continuity in terms of product development and recruitment. Moreover, there is an expectation that older people have the time and inclination to engage in research projects, whereas they lead demanding lives themselves. They often have family or volunteer commitments and medical needs that place constraints on their time and the research process needs to be flexible to accommodate this.

4.3 Managing a Consortium-Based Project

While applied research in AAL requires a multi-disciplinary/multi-partnership approach, this raises practical and operational issues. SOPRANO was a European-wide project that presented logistical issues in terms of meetings and face-to-face discussion that often constrained progress and the sharing of information. Additionally, working effectively within each country was dependent on the local context and each partner required a degree of autonomy as to how the project was conducted. Unexpected issues can occur that prevent partners from making progress, resulting in unexpected delays which can push back deadlines and deliverable dates. This requires a level of flexibility that is difficult to accommodate in a project with fixed objectives and timescales. Moreover, the multiple expectations of the different partners (funding body, project partners, local providers and older people) need to be carefully negotiated to ensure that the partnership is meaningful for all those involved.

4.4 Balancing User Research and Market Issues

The user-centred approach aims to achieve a final product that more accurately reflects the needs of older people. However, whether this process actually leads to a 'more' marketable product is debatable. The SOPRANO experience suggests that user-centred R&D is only useful if it also incorporates the identification of opportunities for knowledge translation and routes to market. Older people are increasingly likely to rely on multiple technologies and systems and the development of new products needs to reflect the complementarity and added-value they provide. R&D should also be based on an understanding of the business processes of personal care delivery. It is unlikely that assistive technologies (at this stage) will be adopted in place of face to face care and ICTs should be seen as part of an integrated spectrum of care [14]. It is also important to be aware of the different actors involved, including older people, service users, formal carers, informal carers, healthcare providers, voluntary and community sector organizations and policy makers. These actors often have competing requirements that need to be carefully negotiated and accommodated for within the R&D process. Moreover, there are deep seated organizational cultures and processes of commissioning care which may provide additional challenges and barriers to the adoption of AAL. Here, there is a need to effectively map existing care services across different cultures at the local level in order to accurately determine the role of technology in supporting existing formal/informal care delivery.

5 Conclusion

User-centred research provides the opportunity for developing assistive technologies which closely reflect the needs of older people and are more context-aware in terms of how older people live their lives. Here, emerging technologies must be flexible enough to reflect the complex nature of routines whilst enhancing the feeling of control for the end user. Technology should not be seen as something which older people need to become more familiar with, but as something that can be incorporated into their lifestyles through better 'personalisation', to allow them to communicate and make sense of the world. Addressing these issues will have a positive impact on levels of compliance and acceptability and their successful integration within the home environment. Additionally, there are the wider barriers to market that assistive technologies face, including its ‘fit’ with other actors, existing models of service delivery and the care commissioning process. The biggest challenge for R&D is how to achieve user-centred product development alongside greater penetration of the market. It should be noted that health and social service providers and funders are highly conservative institutions within society and are resistive to change and innovation. The difficulty encountered in SOPRANO in translating the needs and preferences of older people into viable service models highlights the structural weaknesses within the care delivery systems to meet the wide range of needs of older people. ICTs offer avenues for developing new and innovative solutions for older people that go well beyond existing concepts of elder care.

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A Framework for Service Morphing and Heterogeneous Service Discovery in Smart Environments

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Abstract. The openness and dynamicity of smart environments makes it a necessity to adopt a flexible software architecture. Service oriented architecture (SOA), and more specifically Open Service Gateway Initiative (OSGi), has emerged to be one of the most suitable choices; however, our experience using OSGi exposes its several shortcomings as an SOA platform: 1. The number of services required to be designed and implemented for each sensor, actuator and external system can be prohibitively high; 2. Cross-architecture interaction with non-OSGi software artifacts is challenging and inelegant; 3. There is a need for a more systematic approach to allow mobile devices remote access to OSGi services and enable opportunistic utilizations of local resources. We propose a framework to address these challenges by introducing a mechanism to support morphing a core service implementation of underlying communication protocols and software libraries to customized services using configuration files and a cross-architecture service directory for both OSGi and web services (WS). Our solution allows mobile devices to discover, access and adjust for local resources and results in more open, less cumbersome, and more integrative interactions among computing, communicative, sensing and actuation elements in smart environments.

Keywords: SOA, service morphing, cross-architecture service directory, mobile device support, OSGi, web services.

1 Introduction

Unlike traditional computing environments where configurations are relatively stable and rarely change, smart environments are open systems, where components capable of computation, communication, sensing, and actuating can be frequently added, removed or reconfigured to customize and personalize according to individual user's needs. Such characteristics cannot be efficiently supported by traditional software architectural paradigms. SOA, with the promise of adaptability, reusability, composability, and distributed interactions, among other favorable characteristics, has become a prevalent software architecture in smart environments. However, several issues of existing SOA platforms pose obstacles when used for smart environments.

Obstacle 1: Although SOA encourages software reuse by isolating and aggregating reusable useful functions as a service, in a typical smart environment, there could be

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hundreds or thousands of sensors, actuators, or existing systems and services, which poses a scalability issue in terms of service management and development.

Obstacle 2: Even though all SOAs have mechanisms to register, discover, and invoke services, and can handle dynamicity while improving interoperability between systems, each SOA is limited to services defined and implemented within its framework. Take a smart home implemented with OSGi bundles as well as web services, for example. For a client to locate a particular type of service, it must initiate the discovery process on the service registry at each OSGi platform as well as all the Universal Description Discovery and Integration (UDDI) directories for WS, and then compare the results to select a service to invoke, and invoke selected service based on which SOA the service is implemented.

Obstacle 3: As smart mobile devices become more pervasive, they must become a natural part of smart environment, but current SOA implementations does not provide natural support for opportunistic utilization of the capabilities of smart environments.

There are known workarounds for circumventing these obstacles when using SOA for smart environment implementation, but extra effort is always required. The objective of this work is to devise and create a more systematic solution to eliminate these obstacles and to enable a truly SOA-based solution to support smart environments and mobile devices in them. The final outcome is a cross-architecture framework for service-oriented software discovery, invocation, and composition in smart environments centered on the concepts of a cross-architecture service directory and service morphing.

In particular, we (1) design and implement a mapping from the metadata of OSGi services to UDDI entries, and (2) introduce an automatic mechanism for publishing/ removal of OSGi services to/from UDDI directories. Furthermore, we illustrate the benefits this framework has for developing smart environments through (3) making device services more manageable and (4) improving support for mobile computing devices.

2 Related Work

Apache CXF dOSGi realizes OSGi Remote Services [7], which leverages simple object access protocol (SOAP) over HTTP and exposes the service over a web service description language (WSDL) contract, and grants external software entities access to local services. It maintains only local service registries and the service discovery process requires contacting all known registries separately. However, when worked in concert with Zookeeper, a distributed, replicated and synchronized service directory can be maintained over multiple hosts. Alternatively, the devices profile for web services (DPWS) enables secure web service messaging, discovery, description, and asynchronous communications on resource-constrained devices with minimal implementation constraints, and support universal plug-n-play (UPnP)-like discovery protocols. Dohndorf et al. [8] proposed a mechanism that uses DPWS to bridge isolated OSGi platforms by creating skeletons and proxies for OSGi bundles as DPWS services. This effort emphasizes on more expensive dynamic service discovery protocol while our work attempts to dynamically maintain a centralized service directory for both OSGi and web services with lower overhead.

Al-Masri et al. created the Web Service Repository Builder (WSRB) to accommodate multiple heterogeneous registries, primarily those making use of UDDI and ebXML [4]. However, WSRB is designed only to serve web services. Lee et al. [5] introduced web gateway service in OSGi that allows OSGi services to make use of web services through proxies. In doing so, the OSGi service registry becomes the directory for both native OSGi services and web services through proxies. However, there is no mention of how the relevant web services can be discovered unless already specified in WS-BPEL description. Alternatively, cross-architecture service invocation such as [6] supports mixing services implemented in OSGi, Service Composition Architecture (SCA) and Spring, while using the service registry in the OSGi container as the primary service directory of recommendation. It focused on encouraging interoperability of heterogeneous services, instead of maximizing the exposure and availability of these services to potential clients. Alamo et al. [2] described a composition framework that utilizes a BPEL file to discover and locate best-matched heterogeneous OSGi and web services and mentioned the service registry accommodating both types of services without design and implementation details.

The Atlas Platform [1] supports a scalable, plug-n-play mechanism enabling automatic installation of OSGi software bundles when devices are introduced. This is achieved through storing the bundle in the memory of the Atlas nodes and deploying them when a device connected. Unlike Atlas, our solution does not require modification or addition of hardware devices, but relies only on system configuration at deployment and integration deployment to create services for hardware devices, allowing more flexible administration.

3 Service Morphing

SOA design principles for smart environments would dictate that each individual device and reusable software artifact be implemented with a service. However, one insight we have gained from our smart home development experience is that despite the obvious differences in functions among physical devices they often share more underlying implementation details, such as communication protocols, channels, and libraries, than expected. The idea of *service morphing* uses this insight to reduce code duplication, eliminate redundant libraries, and speed up the service development process by moving towards a “configure and deploy” strategy rather than a “code-and-code-again” strategy.

We design a BundleGenerator (BG) for each family of devices that will be deployed to the environment to produce services for each individual physical device. A *master configuration file* is used to tell the BG the number, type, and properties of individual device services to create and deploy to the OSGi platform. Our solution provides a web-based Configuration UI associated with the hub device to collection information for the master configuration file. For each type of device supported by the BG, a generic bundle is embedded within the BG serving as generic API to that device family. When the BG is activated, it reads the master configuration file, and for each entry therein, customizes a manifest file, a *derived configuration file*, and packages a bundle for the indicated device. The BG deploys and starts the morphed bundle in the OSGi platform. Upon activation, the morphed bundle reads its local configuration file, creates, and registers its customized device service. In this way, multiple device services/bundles can be automatically created and deployed, and, used in conjunction with the Axis OSGi and UDDI-Broker bundles, can automatically be exposed as web services and registered with UDDI.

For instance, by utilizing a core X10 service to send and receive X10 commands and designing appropriate configuration files for the specific device being used (e.g. the X10 device model number and device address for each lamp, radio or sensor, etc.), we enable the core X10 service to morph into services corresponding to each individual lamp, radio, and other device/appliance connected to the X10 hub. This preserves service-oriented design, maximizes reuse, and greatly reduces the cost of implementing device services.

The service morphing architecture is shown below in figure 1, and a sample configuration file is shown in figure 2. The first line of an entry specifies the name, version and symbolic name of resulting bundles, while the second identifies the type and model of the device service to create and relevant device-specific information.

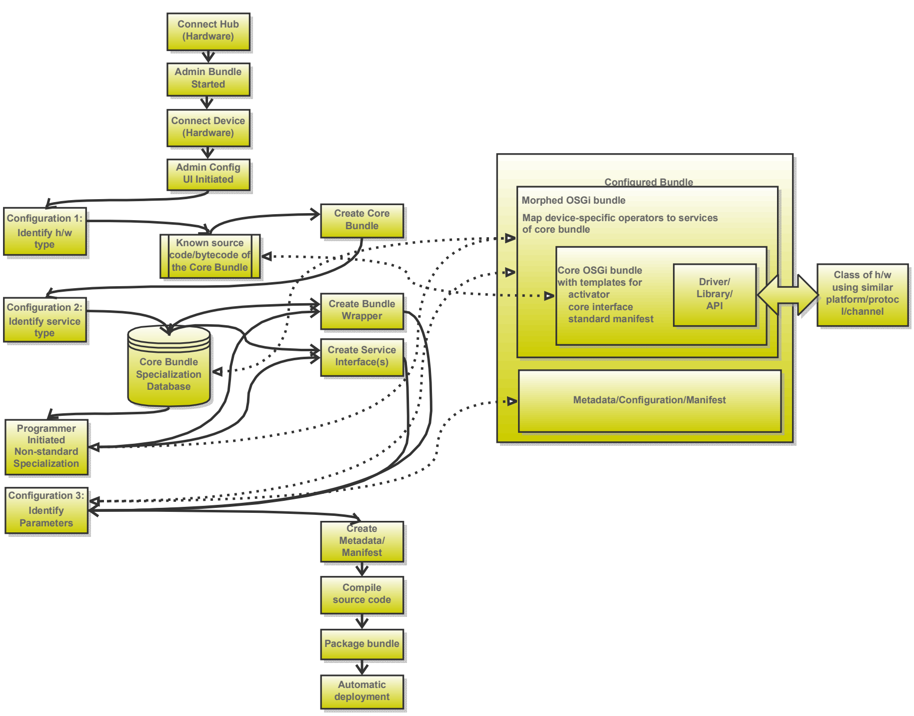

Fig. 1. Service Morphing

```
Phidget.conf
------------------
#Line 1: <Bundle-Name>:<Bundle-Version>:<Bundle-SymbolicName>
#Line 2: DeviceType>:<Model#>:<PhidWebHost>:<PhidWebPort>:<PhidSerial>[:<PhidPort>]

#Light Sensor 1
LightSensor1:1.0.0:edu.iastate.cs.shl.sensors.light.LightSensorService#1
Phidget:1105:eeyore.cs.iastate.edu:5001:12943:3
#Temperature Sensor 1
TempSensor1:1.0.0:edu.iastate.cs.shl.sensors.temperature.TemperatureSensorService#1
Phidget:1114:eeyore.cs.iastate.edu:5001:12943:1

Insteon.conf
------------
#Line 1: <Bundle-Name:<Bundle-Version>:<Bundle-SymbolicName>
#Line 2: <DeviceType>:<Model#>:<DeviceManagerIP>:<DeviceManagerPort>:<DeviceAddr>
#Lamp module
Desklamp:1.0.0:edu.iastate.cs.shl.actuators.lamp.DeskLamp
X10:LM465:celica.cs.iastate.edu:9020:A1
```

Fig. 2. Sample configuration file for supporting service morphing

Though service morphing is similar to the factory design pattern, which creates services upon request based on configuration parameters supplied to the factory, it differs in that, instead of creating services with different implementations, services with the same implementation and different metadata are produced to represent distinct hardware devices. Service morphing has many advantages over naïve service development, including that it reduces the initial implementation of device services from *O(device instances)* to *O(device types)*, enables the reuse of higher-quality, proven software services, and allows dynamic service reconfiguration without modifying and recompiling code. It maintains the concept of SOA by generating a service for each individual device or legacy system component, while reducing the number of core services needed to be implemented and maintained.

4 Centralized OSGi/Web Service Directory

Though web services are the most widely known and adopted SOA to date, many smart environments utilize OSGi. Each SOA platform has its own advantages and weaknesses. On one hand, OSGi is great for the coordination of services deployed on a single host. It also provides better support for security and access control, and makes better use of local resources through sharing of software libraries and packages. It can also perform service interactions more efficiently without the overhead of XML and HTTP and provides a comprehensive mechanism to manage service lifecycle. However, OSGi is limited to Java, and until recently lacked a straightforward way to coordinate services among multiple platforms or support remote discovery from external systems or mobile devices. On the other hand, web services have been designed to be language and platform independent. However, they are rarely used to provide access to local devices and resources, require more complicated manual support and system administration, and have higher performance overhead than similar OSGi services. Since smart environments often involve a federation of local sensors, actuators, as well as mobile devices and distributed systems, a cross-architecture framework combining the strengths of both OSGi and web services would be greatly beneficial. Neither OSGi, nor web services, provides simple and transparent support for cross-architecture service discovery, invocation, composition, or configuration.

Conversion into Compatible Service Registration

The first step to enable cross-architecture service discovery is to define a compatible service registration format. Service registration outlines the critical metadata, attributes and functionalities of the service so it can be searched, compared and invoked. For an OSGi service, its service registration consists of *service interface(s)* defining the operations of the service, a *service instance* implementing those operations, and *service properties* describing the service [7]. Properties of the bundle are given in its *manifest file*. For web services, registering with UDDI, an XML-based directory for distributed web services, requires declaration of five data structures: *BusinessEntities*, *BusinessServices, BindingTemplates, TModels* and *Publishers.* In particular, *BindingTemplates* describe individual web services and their metadata, and *TModels* provide namespace, value space, or technological identifiers for UDDI artifacts. The generality and flexibility of the UDDI data structures allow us to map OSGi services registrations to UDDI entries, as shown in Table 1. It enables services from multiple OSGi platforms to be published to one centralized UDDI server. Non-OSGi and non-Java clients can query, bind, and invoke OSGi services on remote hosts if they are exported as web services via Apache CXF dOSGi or *Axis OSGi* bundle in Knopflerfish OSGi. Based on the TModel, the invoking service can differentiate whether the discovered services are available via OSGi or WS, and invoke/integrate them accordingly. The *BindingTemplate* provides an *access point* for the generated WSDL, *instance parameters* derived from the OSGi service's properties, and *overview documentation* generated from the Bundle-DocURL manifest value.

Table 1. Mapping between OSGi and UDDI service entries

OSGi bundle	Service entry in UDDI
Bundle Vendor and ContactAddress	BusinessEntity (as Service Designer/Developer)
OSGi platform	BusinessEntity (as Service Provider) and Publisher
OSGi Bundle	BusinessService (grouping of related services)
Service Interface	TModel (as Service type identifier)
Service Instance	BindingTemplate (w/ access point, overview documentation)
Service Properties	Instance Parameters

Automatic publishing of OSGi service registrations to UDDI

The OSGi platform provides comprehensive facilities for service lifecycle management, so it can handle dynamic events such as bundle (de-)registeration or modify of bundle properties via callback functions. To enable truly seamless integration between OSGi and web services, this capability must be extended to the (de-)registration with the UDDI directory. A *UDDI-Broker* bundle is introduced in each individual OSGi platform to automatically publish OSGi services to a pre-configured UDDI directory when they register with OSGi and removes them from

UDDI when they deregister. By eliminating the manual effort usually required to administer web services; hosts and mobile devices can discover and use services without manual intervention. The automatic registration of OSGi to UDDI is illustrated below in figure 3. One note of particular interest is that in Step 5', the UDDI-Broker must check to make sure there is no duplicate *BusinessService* or *TModel* entries, however, *BindingTemplates* are always created for each individual service registered. When the OSGi services are unregistered, the corresponding *BindingTemplates* are removed from UDDI, but the *TModel* and *BusinessService* entries remain until no references to those structures exist from other OSGi bundles/platforms.

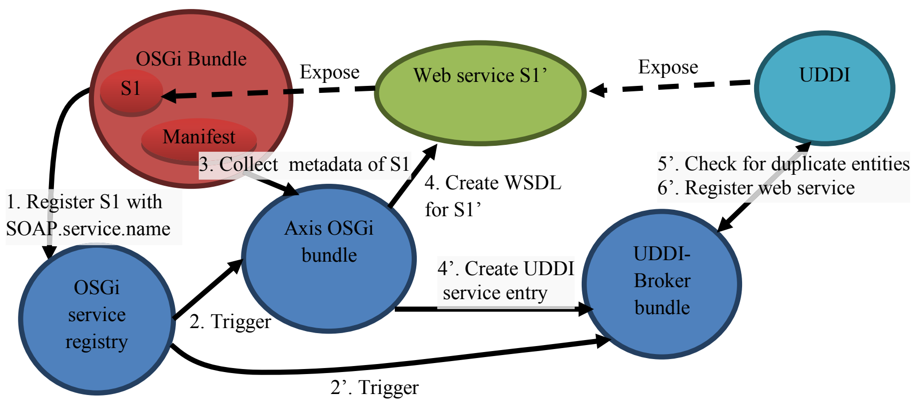

Fig. 3. Automatic publication of OSGi services to UDDI

Support for Mobile Devices and Location-Awareness Implications

Automatic exporting OSGi services as web services and registering with a centralized UDDI service directory enables SOAP-capable mobile devices to discover and access them in a standardized, platform-independent manner. This by itself already presents significantly improved support for mobile devices, which is previously limited to utilizing proprietary communication protocols within each OSGi service.

With slight modification, our solution permits mobile devices to find *locally available* devices and services if location information is embedded within the master configuration files and carried over into the corresponding service registrations as part of the *BindingTemplates*. Alternatively, without specifying location information of each device, we can publicize only the whereabouts of each OSGi platform in the corresponding *BusinessEntity* description. Since registering a service with an OSGi platform would often imply a direct physical connection to the platform (e.g. through USB), a command and communication channel (e.g. through gateways), or a digital footprint that utilizes the computation, communication or storage facilities on the host of the OSGi platform, it can be inferred that the services registered with a OSGi platform has high probability to be within a relatively close proximity. Therefore, in order to find nearby devices, the mobile client can query *BindingTemplate* entries to find the OSGi service registry, and to find nearby services, the mobile client can query *BusinessEntities*. Either can then be accessed with the published WSDL URL. This enables mobile devices to opportunistically retrieve more meaningful data (e.g.

temperature in the mobile device's room rather than another room/building), while encouraging utilization of local resources to improve performance (e.g., speed, power consumption or bandwidth) in the spirit of cyber foraging [3].

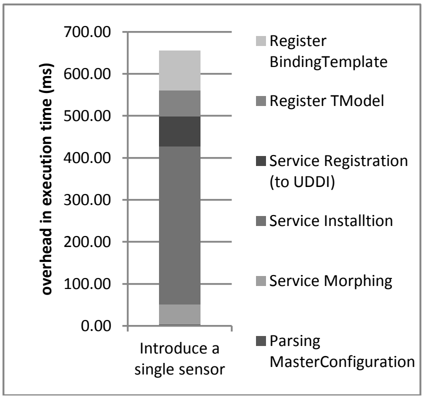

Fig. 4. Performance Profiling

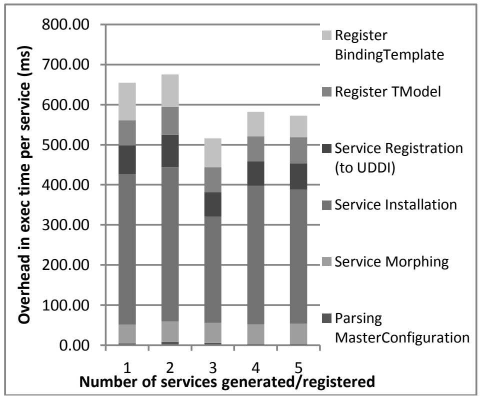

Fig. 5. Constant overhead per service

5 Performance Evaluation

To understand the performance overhead of the service morphing and the cross-architecture service directory, we have conducted a series of experiments. The experiments were conducted using a Dell Inspiron 1525 laptop running 32-bit Windows Vista, with an Intel Core 2 Duo T8100 2.10 GHz processor and 3 GB of RAM. For the experiments, all OSGi services are deployed to a local instance of Knopflerfish 2.2 OSGi platform with Apache jUDDI 3.0 (backed by a MySQL 5.0 database) also installed locally. The UDDI contained no services at the beginning of each execution. The OSGi services generated via morphing are various analog sensors (light, temperature, pressure, etc.) connected to one Phidget 8x8x8 interface kit. Fig. 4 and Fig. 5 above summarize our findings. It takes less than 0.7 second to morph a service and register it in UDDI, which represents a very reasonable overhead, and, furthermore, this per-service overhead remains constant regardless of the number of devices connected.

6 Conclusion

SOA enables flexibility and dynamicity while encouraging software reuse, making it particularly useful in smart environments. However, the support for implementing smart environments with the currently available SOAs is inadequate. To reduce related costs and improve efficiency, existing services and artifacts should be reused, regardless of the language, platform, or SOA in which they are implemented. Similarly, the number of services designed and implemented should be minimized while still providing services reflecting the true functionalities and capabilities of devices and libraries.

We have implemented a framework for service-oriented software discovery and composition in smart environments based on service morphing and a cross-architecture service directory. It reduces the development burden when creating new devices, seamlessly integrates services from multiple architectures, and facilitates interaction with mobile devices. The result is a cross-architecture framework with improved reusability, scalability, and platform-independence in complex smart environments.

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Impact Analysis of Assessment, Consultation and Education Services to Support the Adoption of Smart Home Technologies, Innovations for Chronic Disease Prevention and Solutions for Independent Living

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Abstract.
Aims: To review the impact of the services of LifeTec, a NFP (not-for-profit) state-wide community-funded provider of assessment, consultation and education services to support the adoption of smart home technologies, innovations for chronic disease prevention and solutions for independent living.

Methodology: a review of service data collected by LifeTec and independently evaluated

Findings: LifeTec and other similar ILCs (Independent Living Centres) in Australia and other countries, provide an assessment, consultation and education service that is critical for people with disabilities, the frail aged and others needing support. The services are accessed by consumers, their families, care provider organisations, clinicians and educators; the needs for these services are far greater than currently-funded capacity and there will be a need for greater capacity as baby-boomers move into the ages when needs for support will spiral upwards.

Summary: The disability support and aged care sectors have not to date taken advantage of assistive and other relevant technologies; there is a massive unmet need for greater support and a significant level of issues that are not addressed. There will need to be a significant increase in funding of ILCs to meet both existing needs as well as to surge at appears to be changing and there is now significant investment in clinical systems and other systems to assist staff in providing care.

Keywords: information technology, assistive technology, disability support, independent living, aged care, seniors, workforce.

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1 Introduction

There is growing interest in the adoption of ICT to assist in the delivery of care for people with disabilities and the frail elderly [1]. Challenges associated with demographic changes include rising consumer demand, workforce availability and skill levels, and providing services across the vast geographical spread of the disability services and aged care population and location of services. These challenges promote the need to investigate and implement new models of care delivery through ICT[2] and previous research has identified opportunities for ICTs [3] [4].

2 Ageing and Disability

Australia shares the concerns of most countries of the world that are experiencing the impact of an ageing population and its associated illness, disability, and needs for support.

Technology is anticipated to offer significant potential for equipping societies to respond to these pressures [5], [6]. Applications include assisting older people in extending active and independent lives, maintaining consumer productivity, better managing and supporting the care workforce and in delivering and increasing the quality of care in home, community and residential care settings. Globally there is an increasing level of activities, strategy development, research projects, and adoptions of telecare, telehealth, smart homes and assistive technologies by consumers and care provider organisations [7]. Technologies offer an array of benefits including a reduction in hospital admissions and length of stay. [8], [9].

3 Smart Home and Assistive Technology

There is recognition of the potential for technology to enhance the safety and independence of older people, enable access to care services, extend their ability to remain in lower levels of care such as their own home, and to address workforce productivity and availability. Intelligent monitors can keep a continuous watch on vital signs, activity patterns, their safety and security, and provide early warnings of potential problems [10]. Automation is expected to enhance security, safety and independence [11]. This could help maintain quality of life and decrease the demand for carer support hours.

There is much research or demonstration models with the aim of promoting the adoption of ICT for care [12], [13]. In the state of Queensland, Australia, a model for referrals of suitable people away from hospital admission to community disability services and aged care has been evaluated indicating that such systems could significantly reduce avoidable hospital admissions [14]. There are similar initiatives around most Australian health jurisdictions for managing Emergency Department demand.

Research into technology adoption issues, return on investment, realisation of benefits, integration and interoperability is required to ensure a sustainable system. Current evidence indicates that the level of adoption of technology in disability services and aged care services remains low. There appears to be many factors influencing this and these are seen to include low awareness, attitudes to technology, design issues, telecommunications capacity, technical support, overall cost and uncertainty that benefits will be realised.

An indication of the extent of new technologies available to ageing services and related research is available from the web-site of the Center for Aging Services Technologies [15]. A new centre in Ireland, Technology Research for Independent Living (TRIL) is using ethnographic approaches to better understand seniors' attitudes to technology [16].

4 LifeTec

LifeTec is a leading provider of specialist information, consultation, and education on assistive technology that can help individuals improve their quality of life and remain independent. Through a health professional service delivery model, LifeTec provides advice on the range of available solutions regardless of a person's age or level of ability. LifeTec assists a wide range of people from all walks of life. Its clients include older people who wish to remain independent in their homes for as long as possible, as well as children and adults with chronic conditions or a disability.

Some of LifeTec's clients have health issues as a result of ageing or illness and simply want to make life easier. LifeTec's health professionals assist people to maximise their independence and their ability to manage everyday tasks whether in the home, workplace, or out in the community. They specialise in matching peoples' needs and wants with the most appropriate assistive technologies by applying clinical reasoning in different contexts, including human, technology and activity contextual factors.

The majority of LifeTec's funding is from the government at both a Commonwealth and State level. It receives funding from the Australian government's Home and Community Care (HACC) scheme as well as from state government: Disability Services Queensland and Queensland Health. LifeTec also derives income from its private consultation and education services.

LifeTec also works closely with Indigenous and culturally and linguistic diverse (CALD) communities to tailor services and promote the unique needs of different groups. LifeTec's access to cutting edge assistive technology enables it to provide up-to-the-minute advice and practical, hands-on experience of the latest equipment, devices and aids to suit individual needs. LifeTec operates display centres in Brisbane and Townsville and also has a state-wide outreach service across Queensland.

5 Specific Services and stakeholders

LifeTec provides a number of services to the community. These include information, consultation and education on assistive technology. Information services are provided via face to face, email, phone, or from one of its display centres located in Brisbane and Townsville. These displays feature more than 2500 assistive technology items. Consultation services are provided in instances when an assessment of a person's assistive technology needs and wants is required. This involves an in-depth assessment and trial of technology solutions to meet a person's goals. Education services include raising awareness of assistive technology and its benefits, and targeted workshops for health professionals in specific areas of technology. In addition, LifeTec provides a range of Information, Consultation and Education services on an outreach basis across the vast area of the Australian state of Queensland.

Of interest to this research, was LifeTec's Consultation services which is provided to consumers and their families and carers. This involves a consultation between a consumer and a LifeTec health professional as the consultant. The consultant undertakes an assessment of the consumer's clinical conditions, goals, and other contextual factors. The consultant is able to select and trial different technologies with the consumer to see if it meets their wants and needs. At the end of the consultation, the consumer is usually provided with a prescriptive report of recommended smart home and other assistive technologies with details of suppliers. A specific area of focus to this research, was LifeTec's access and home modification tele-consultation services. This specialist service assesses the access and safety of peoples' homes in rural areas by using Skype. A local officer facilitates a tele-consultation process by using a tablet directly from the person's home and communicating in real time with one of LifeTec's health professionals situated in one of its centres. Using different home modification apps, the consultant can often make recommendations and send these to the facilitator on site. Modifications to the person's home can then be performed with minimal delay.

LifeTec's stakeholders include relevant federal and state government agencies, aged and disability care provider communities, consumer bodies, carer associations, clinicians, researchers and the community generally. There are almost 3 million Australians aged 65 and above; most of these are healthy and independent but around 1 million people of all ages, mostly seniors, receive some types of care and support in their own homes. These are the core target group for LifeTec's services as well as carers, families and care provider organisations.

6 Methods

LifeTec records service and client data as part of its client records. The units recorded in Table 1 were occasions of service provided by LifeTec health professionals to a member of the public or other professionals. Consultations cover all assistive technologies available that might assist the consumer. These included ambient, wearable, remote monitoring, universal design, as well as speech pathology, occupational therapy and physiotherapy. Consultations focused on specific areas of functional independence that improved the ease and safety with which people undertake daily activities. These include residential, vocational, educational and recreational activities and goals.

The research showed there was a rapid continuing increase in the use of LifeTec for consultations.

The data gathered over the two calendar years 2010 and 2011 was gathered, reviewed and compared (Table 1).

Table 1. LifeTec service statistics 2010 and 2011

Data Collected	2010	2011
Total number of service delivery units	22,496	24,858
Client gender	56% female 44% male	54% female 46% male
Client location	83% metropolitan 17% rural	72% metropolitan 28% rural
Average waiting time for rural client consultations	52 days	17 days
Indigenous and CALD clients	4%	7%

Service delivery units include consultations or other occasions of service to clients. The data shows:

- The total number of service delivery units increased from 2010 to 2011by 2362 (24,858 – 22,496), representing a 10.5% increase in services
- A slight increase in services to male clients from 44% in 2010 to 46% in 2011
- A significant increase in services delivered to rural clients from 17% of total services in 2010, to 28% of services in 2011
- Average client waiting times for LifeTec services reduced by a significantly from 52 days in 2010 to 17 days in 2011
- Indigenous and CALD (culturally and linguistically diverse) client numbers grew from 4% in 2010 to 7% in 2011

7 Findings and Discussion

The data shows that LifeTec service delivery has continued to grow by over 10% per annum. To meet this growing need, LifeTec has implemented the following strategies:

- Established Smart Homes in Brisbane and Townsville
- Introduced specialist tele-consultations
- Established an additional assistive technology centre in Townsville

The response of LifeTec management has included:

- The provision of specialist services to an additional 2362 Queenslanders as a result of the strategies introduced.
- An increase in the percentage of male clients accessing LifeTec services (44% in 2010 to 46% in 2011). This is likely to be a result of the holistic provision of AT solutions under an ambient living model by utilising Smart Homes for the prescription of AT. This approach has increased uptake of AT for wider range of disabilities, chronic conditions and even recreational activities.
- A significant increase in the number of services provided to rural clients across Queensland (17% in 2010 to 28% in 2011). The introduction of specialist tele-consultations was the main cause in the increase of service provision to rural clients. Tele-consultations also resulted in increased continuity of care, improved access and reduced waiting times. The establishment of a second LifeTec AT centre in Townsville (1,400 km north of Brisbane), also contributed greatly to the increase in service provision to rural clients.
- Tele-consultations also resulted in very large reductions of client waiting times. Waiting times for specialist LifeTec services vary significantly in metropolitan and rural areas. Average client waiting times were reduced by 67% (52 days in 2010 to 17 days in 2011). LifeTec's second AT centre in Townsville also contributed to this significant reduction in waiting times.
- LifeTec grew its service delivery to Indigenous communities from 4% in 2010 to 7% in 2011. We attribute this primarily to the establishment of LifeTec's second AT centre in Townsville in north Queensland. This area has a higher Indigenous population than southern Queensland, which has enabled our health professionals to network and establish more effective relations with Indigenous communities.

8 Conclusion

Most people have become familiar with and have adapted to technologies that are now pervasive across industries. This research set out to refresh previous research and to determine the degree of change in investment in ICT in disability support and disability services and aged care services in Queensland. A review of data collected by LifeTec, the state's independent living centre was undertaken.

The research found that client demand for AT services continued to grow at over 10% per year. To meet this growth, LifeTec introduced new initiatives including smart home delivery models, specialist tele-consultations and established a second AT centre in north Queensland. In 2011, these initiatives resulted in 2362 additional service delivery units, an 11% increase in rural services, a 67% reduction in average client waiting times and an increase in Indigenous services from 4% to 7%.

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Ensuring a Fruitful Future to Innovation and Research: Practical Guidance for the Involvement of Older People in Research

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Abstract. Projects and policies geared towards people, especially older people and people with disabilities, should be oriented by real user needs. They are indeed critical when developing effective and efficient products, services and policies. While research and technology can continue advancing on their own, they will have very limited impact and will result in minimal – if any – benefits for society, if user involvement is not taken into consideration The collaborations between users and their representatives with industrial stakeholders, academics, policy-makers and all actors involved in developing and improving our societies can provide a thorough understanding on the benefits, challenges and different levels of user involvement. Focusing on the challenges for our ageing society, this paper's ultimate aim is to show that allowing older users to express their needs at all stages of research results in solutions that respect the principle of design-for-all and has a greater impact to society in general.

Keywords: user involvement, ageing, older people, research, innovation.

1 Introduction

Ageing research is increasingly becoming a political and scientific priority and the involvement of older people has gained significant attention both in the research and policy field. This approach towards involving users "*reflects the democratic approach to participation (…) being able to improve the quality of their lives*" [1]. Information and communication technologies (ICT), eInclusion and Ambient Assisted Living (AAL) hereby play a central role, both in connecting older people's lives with research experiences, and in improving their quality of life.

AGE Platform Europe (AGE) is finalizing[1] a concise and practical guideline putting forward principles and recommendations for user involvement that can be readily adapted by relevant stakeholders in their work. Building upon literature evidence, input from research projects[2] as well as drawing from its own work in this

[1] This is a work in progress which could be hopefully finalized by the end of 2012.

[2] Mainly 7FP and CIP PSP Research Projects working in the realm of ICT and health and accessible mobility, listed here: http://www.age-platform.eu/en/all-projects. AGE's involvement in those projects inspired a previous document on user involvement [2].

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field[3], AGE has the ability to fill in some gaps and clarify the case for user involvement developing a toolkit addressed to researchers and project coordinators, older people's organizations and individual users, policy makers and public authorities.

2 Older People as Users

The word 'users' is sometimes used rather vaguely. In addition to this, literature and practice also use the terms 'primary' and 'secondary users', 'end users', 'direct users', 'beneficiaries' etc. In a very broad context, users are a group of people who are expected to benefit from the developed service, product, technology or policy. In some European projects[4], designers and developers of technologies are also conceived as "users", exploiting the same technology they are contributing to. In order to denote older people from developers, the word "beneficiaries" has been introduced to specify their role as the final users. Depending on the purpose of the research, the target group must be clearly defined. Researchers need to take notion of these different interpretations and decide which is/are the target group(s) that they should involve to achieve better research results. Users are not a homogeneous group: innovating for an ageing population implies encompassing persons with different age, sex, ethnic and geographic origin, social and cultural backgrounds. Furthermore, they vary greatly in cognitive and physical abilities, and have different approaches and familiarity to technologies developed or services studied. Particular attention must be paid in order to avoid excluding marginalized users and/ or treating different situations in the same way: for instance, old age can span 20, 30 or more years so treating users over the age of 60 as a single group is unlikely to give rise to generally applicable findings. Thus a further 'filtration' of the user groups is essential. Restructuring smaller age-groups is considered necessary in order to respond to real-life situations. In addition, equal inclusion must be addressed: gender issues, situations of low income, the lack of access to transport, disabilities or low self-confidence must also be taken into account.

In order to capture the heterogeneity of users and to ensure that all older people have equal opportunities to participate, an inclusive approach to user involvement is essential.

3 Why Involve Older People?

Users have experiences, skills and abilities that complement the knowledge and expertise of researchers and policy makers [3]. Involvement of seniors becomes

[3] AGE's field of activity encompasses a broad range of issues sensitive to older people, from social inclusion to employment, universal design, ICT and intergenerational solidarity: http://www.age-platform.eu/en/age-policy-work.

[4] This was the approach used within the Veritas project (http://veritas-project.eu), co-funded by the European Commission – 7th Framework Programme. The Veritas case has been chosen here as example covering most of the issues around user involvement this paper aims at pinpointing.

particularly relevant for users, researchers, industries and public authorities as they constitute an important society and market segment that stakeholders can no longer ignore. Of course user involvement is *not a panacea*; additional effort and resources are required, which may also delay research outcomes and decision making. So why involve users? What are the expectations of those engaging older people in their research? Understanding *the impact of user involvement* is essential because the different reasons for involving seniors may affect the nature and the extent of user engagement [4].

While innovation and policy can advance on their own, this section argues that *genuine user involvement*[5] can bring an added value to research, policy and practice. Market deployment of the developed products and services is facilitated as real needs and problems are addressed; this obviously translates into cost benefits for the society as a whole. In addition, participation insofar as it means that older people are respected and feel valued is a key component of seniors' wellbeing. In particular, older people can benefit from being involved in research in the following ways:

- They are informed about research which concerns them directly, such as innovative solutions for everyday life;
- They become familiar with processes and methodologies and may even acquire new knowledge, skills, and have the possibility to develop organisational, interpersonal or other skills;
- They have additional opportunities for social and political participation. In this sense they do not feel exploited by research and may gain confidence that they can influence the political and research scene.

Genuine user involvement also means that:

- Research ends up in results which are relevant for older people and which can be used in policymaking. As a result the quality and applicability of research is improved [5];
- Risk of ageism is avoided because older people are seen as valuable experts;
- Resources are invested on research which is important and can have an impact on the lives of older people.

In addition, if user involvement is organisation-based, a better dissemination of research outcomes may be achieved through the well-established network of contacts between older people's organisations.

4 Levels and Methods of User Involvement

There are various stages and levels of user involvement in research and some theoretical categorizations which may serve as models. However, in reality different

[5] The term *genuine user involvement* refers to user involvement which is *meaningful and productive* because it can influence research set-up, development and outcomes as well as decision-making in the policy field. It means conducting research or policy-related studies not *for* or *about* seniors, but *with* older people, or even undertaken by users themselves. In sum, genuine user involvement means that users are not involved only as subjects of the undertaken study but they assume an important role in it.

methods and levels of engagement may co-exist. Of course, all approaches have strengths and weaknesses. For instance, while user-led initiatives give a strong say to older people and have the potential for making fundamental changes (as older people are not only asked to evaluate but also to come up with new ideas), funding and resources can be problematic. Research led by public or private entities is more likely to reflect already established biases and research agendas, thus potentially limiting its impact, but at the same time it may gain financial and other type or formal support and credibility [6].

Users may be involved at all research phases, from framing a research question to disseminating results and being part of a potential follow-up of the project. Obviously, there is a huge difference between distributing a questionnaire to older people and undertaking research where users are asked to play an active role. Some examples of user involvement include the establishment of *User Fora*, *Advisory Boards* and *Focus Groups*. The method that will be followed depends on the purpose of the conducted research as well as the available resources. For instance, both the first and the second ones (*User Forum* and *Advisory Board*) were chosen by two large-scale integrating projects, Oasis and Veritas[6]. While Advisory Boards include high-level experts in project-related domains, User Fora gather the final beneficiaries of technology (older people and people with disabilities) to test ideas, products and services. The Veritas and Oasis projects promote the participation of older people coming from the local communities involved in the project pilot sites, alongside beneficiaries' organisations at national and European levels, thus ensuring that a diverse sample of user views is taken into account, thus providing a broad range of inputs.

From different perspectives and backgrounds, both bodies have been created to provide expertise, know-how and concrete feedbacks on the project general outcomes and on its applications and developments.

Even though there is no one-fits-all solution, as it has been demonstrated by various projects[7], *early user involvement is the best option for evidence-based research*. In fact when user participation comes at a later stage when the technology, product or service has already been concretized, there is a higher risk that the feedback from the users will not be implemented, especially when it requires fundamental changes in the prototypes which would result in significant additional costs.

5 Challenges for User Involvement and How to Overcome Them

Genuine user involvement is quite complex and encompasses many challenges: it means overcoming barriers, enabling people to use their own voices, engaging in a

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[6] Both co-financed by the European Commission under the 7th Framework Programme, more information can be found on the web: http://www.oasis-project.eu/ and http://veritas-project.eu/.

[7] Among others: ERA-AGE, FORTUNE, USEM, FUTURAGE, Dreaming, Mediate. Through various workshops gathering different users, all projects stressed some difficulties in coping with conflicting needs and pointed out the importance of targeting scope, tasks, language, etc. according to the audience.

long-term creative dialogue with users, recruiting experts to carry out sociological work, etc. Meanwhile ICT and ageing raises new ethical questions related to the vulnerability of the user, the changing characteristics of the user population, budget constraints and the constant development of science and technology [7].

Planning User Involvement

Meaningful involvement in research requires planning and adequate resources; otherwise it is no more than a tick box activity. Preparing user participation includes refining legal, ethical and practical risks, defining roles and responsibilities for all parties, deciding on methodologies as well as timing and budgets.

User participation should be facilitated by various means: providing people with the necessary support and/or training; distributing material in a language and format that they can easily understand; making arrangements so that they feel comfortable and knowledgeable about the research issues, so they are able to participate effectively in the process; engaging qualified researchers who can encourage them, help them understand and observe them in real-life conditions in order to appreciate older people's needs. As some participants may lack confidence or familiarity with the methodologies used or the topic studied, empowering people to use their own voice is a crucial factor.

With this respect, the experience gained within the Veritas User Forum[8] is worth being highlighted. The agenda of the User Forum was intentionally designed to target both project beneficiaries and end users[9] and to allow time for explanations and interaction on the project applications to be developed. After a common introduction, which aimed at explaining in user-friendly words the contents of the project and the forum, the second part of the meeting foresaw two sub-sessions, one dedicated to the end users, and the other to the beneficiaries. The planning of this meeting differed from the previous user forum, where both target groups were asked to discuss together about selected items. Given the highly technical contents expressed in the project, the best solution to guarantee effective user participation was found through splitting the forum into two sub-groups, in order to encourage active participation and thorough discussions within each group. The concluding session gathered again both groups allowing a cross-evaluation of the outcomes as perceived by beneficiaries and developers. This model was welcomed both by the external participants and the Veritas partners, and it will very likely be followed in the future as well. Nevertheless, the experience in Veritas shows that, despite the efforts for setting up a moment of direct dialogue among the parties, genuine user involvement is indeed challenging: besides providing users with supports, dedicated materials and resources, engaging users means also to find a common language, in order to establish a real communication and thus a fruitful interaction enriched by the mutual dialogue.

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8 Second Veritas Users' and Beneficiaries' Forum, 19 September 2011, Nottingham (UK): http://veritas-project.eu/category/news/veritas-events/user-forum-veritas-events-news/.

9 According to the terminology used within the Veritas project, "beneficiaries" are the real users of products and services, while "end users" is a term designating the designer and developers of products and services.

Furthermore, limited time often hinders meaningful user involvement. Planning should ensure that timescales for involving users (for recruitment, participation and evaluation) are realistic. Sometimes the need for user involvement funding is underestimated: users are often expected to contribute with their time and expertise for free while project partners get paid for their contribution. While remuneration might be envisaged, especially for long-term user engagement, users are often motivated to participate on a volunteer basis, as long as their basic expenses are covered. However, users should not be asked to pay any extra fees for participation in the project. If some of the users need personal assistance, special arrangements should be made to support their participation by covering all or at least a part of their expenses.

When searching for a suitable venue, accessibility issues should be addressed. Especially when working with older people, providing a place with sufficient air and lighting, accessible entrance and clean toilets is particularly important. Regarding the organization of meals and coffee breaks for participants, dietary needs should not be neglected. In addition the food should be adequate and culturally appropriate.

When planning user involvement, all relevant legislation, regulation and ethical codes should be taken into account; it must be defined in details how these provisions will be met in terms of processes, timing and responsibilities and it is important to raise them during the planning phase, to avoid potentially negative, even legal ramifactions.

Some key ethical concerns include the following:

- Consent of the end-user
- Objectives of research and benefice to the user
- Safety
- Independence of research and researcher
- Respecting decisions, dignity and integrity of user
- Gender balance
- Equality
- Privacy and data protection

Copyright issues have to be clearly defined, including whether users can utilize the acquired information and knowledge. All those participating in the process have to be able to see the outcomes of their contribution.

The provisions regarding the lawful processing of personal data must be respected even if the users have given their consent, especially regarding sensitive data. As European States may interpret the scope of the European instruments quite differently, special attention should be given to national legislation[10].

[10] On 25 January 2012, the European Commission launched a Proposal for a Regulation of the European Parliament and of the Council on the protection of individuals with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation) which would alter the data protection framework imposing new requirements to data controllers and ensuring harmonisation of data protection across the European Union.

To avoid risks related to the processing of personal data such as identity theft, profiling or constant surveillance, the principle of proportionality has to be respected. Data can be used only for the initial purpose for which they were collected. Anonymization or pseudonymization are ways to prevent violations of privacy and data protection rules. Processing has to be limited to what is truly necessary and less intrusive means for realizing the same end have to be considered.

Recruitment

The selection and recruitment of users is a crucial part of the user involvement process: depending on the subject of the study undertaken, the target group and the representativeness of users have to be clearly defined. Representativeness may depend on some of the following factors:

- Age
- Socio-cultural and ethnic backgrounds (profession, ethnicity, nationality, community, etc)
- Physical and cognitive ability
- Sensory ability (hearing and vision)
- Personal circumstances (living arrangements, income, etc)

Besides, when selecting users, the risk of high percentage of drop-outs should be taken into account, especially when dealing with older people and frail users[11]. To enhance user participation and avoid last-minute withdrawals, users need to agree on the ethical code managing the trial and to be informed and trained to the use of prototypes of devices and services before the beginning of the trials. Using appropriate language and modes of communication are also important factors in the recruitment process. To approach users, linguistic and cultural differences need to be addressed; personal contacts, meetings in local communities, telephone discussions are good alternatives to emails which in most cases can reach only a small part of the senior population. Another good practice is the use of peers, professionals, younger people that the involved users can trust and whose experience can encourage them [8]. In order to induce motivation it is essential to make users understand that their contribution is valued; knowing how their opinion will be used to make a change, will persuade people to get engaged.

User Involvement in Practice

Striking a balance between users' and researchers' knowledge, experience, priorities and expectations is definitely not an easy task. It requires a lot of time and commitment but at the end it will have the most important effect on the quality and the impact of the undertaken activity [9].

The stakeholders involved need to build a partnership based on respect; trust among the different parties has to be ensured from the early beginning and users

[11] The Dreaming project (Elderly Friendly Alarm Handling and Monitoring) experienced the impact of drop-out in clinical trails. A consistent revision of the trials became necessary and it led to the remodeling of timing, budget and trial's structure, too. More information: www.dreaming-project.org

should be treated like experts. This includes, being flexible on the agenda as topics which were not decided by researchers may arise. Unless, users are given the possibility to significantly alter what has been already defined and decided before their participation, one cannot claim of undertaking genuine user involvement. Differences and gaps in communication is a central issue that needs to be addressed. Concepts need to simplified and explained; users need encouragement to say what they want but also guidance to avoid ignorance; observing and empowering older people is an essential element for effective user involvement; narratives or dramatization may also be used to stimulate discussions. Users should also have the possibility to opt-out and this is not necessarily a failure; on the contrary, it should be valued and analyzed, as the opt-out can say more than an unfruitful involvement.

Alongside a good relationship between researchers and users, disseminating results broadly through various appropriate channels and engaging users in evaluation and peer review processes are essential elements for efficient innovation [9].

6 Conclusions

User involvement is an important but complex issue. First, older people are not a homogenous group; researchers should aim to conduct research designed to be inclusive and representative of various user groups. Second, the methodology for user involvement depends largely on the discipline and the study design. Besides, undertaking interdisciplinary research is a challenging field that requires optimal cooperation among the different stakeholders.

Older people should not only come to validate the research question; their role should be gradually enhanced: from subjects of research, to active participants and further on to framers of the question and co-designers of research. Besides guaranteeing user involvement at all stages, ethical and legal concerns should also be tackled. Indubitably, personal contact is essential when working with older users as well as empowering them to understand and use their own voice to express needs and ask questions. The role of user organizations is particularly important as well as undertaking a plan that ensures sufficient time and resources for user involvement. Last, collaborations between the research and the user community should be promoted, increasing in the meantime the opportunities for dissemination of the research outcomes.

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Fostering a Continuum of Care

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Abstract. Healthcare is facing demographic and socio-economic challenges: from an ever ageing population suffering from chronic diseases and various handicaps to the need for affordable "global" healthcare provided by fewer and fewer professionals and medical infrastructures. "Many healthcare systems around the world will become unsustainable by 2015. The only way to avoid this critical situation is to implement radical changes"[1]. Information and Communication Technologies could offer a way of changing how healthcare services are delivered to the citizens and could represent an effective tool to cope with these challenges.

The CHIRON project (Cyclic and person-centric health management: Integrated approach for home, mobile and clinical environments) is a European research project of the ARTEMIS JU Program and addresses these issues. Its main focus is on prevention i.e. on a move away from 'health care' towards 'health management', from 'how to treat patients' to 'how to keep people healthy'. CHIRON designed a system's architecture making possible a *"continuum of care"* i.e. an integrated health management approach in which health is patient-centric at home, in the hospital and in nomadic environments. Care is moved from the hospital to the home and the healthcare staff is enlarged by adding informal carers to the medical professionals and by motivating and empowering the patient himself to manage his own health. The CHIRON system builds a personalized risk assessment of the patient by integrating personal information, data gathered at home and in a mobile environment through an innovative set of wearable sensors, data available at the hospital including outcomes of image-based tests. The expected results are a reduction of the healthcare costs and a better quality of care.

Keywords: Personal Healthcare, At home care, Continuum of care, Remote monitoring, CHIRON project, e-health, person-centric, prevention.

1 Introduction

Healthcare is facing demographic and socio-economic challenges: population is ageing and in parallel the quantity of people with chronic diseases (often with co-morbidities) is growing, migration of people across the overall world is determining a "globalization" of healthcare, specific diseases are no longer restricted to some geographical regions and this will ask for a more knowledgeable medical community,

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citizens are becoming more demanding in terms of quality of care and well-being. Healthcare costs are exploding and there is a shortfall of medical professionals and medical infrastructures. To cope with these challenges major changes will be needed in the delivery and management of healthcare. Healthcare needs to move from treatment to prevention; the possibility of monitoring chronically ill patients without having to accommodate them in the hospital is an exciting proposition for the National Healthcare Services in Europe.

Healthcare – traditionally focused on institutional care and on curing diseases (diagnosis, treatment) – needs to shift towards monitoring and early detection and management of chronic diseases; the aim is to reduce – at least – the occurrence of complications.

CHIRON (Cyclic and person-centric health management: Integrated approach for home, mobile and clinical environments) is a European research project of the ARTEMIS JU Program and is addressing these issues. 27 Organizations from eight European member states and representing the industry (large companies and SMEs), the research and the academic communities and medical institutions are involved. Having started in March 2010, the project has a term of 36 months and a budget of 18 million Euro.

CHIRON intends to combine state-of-the art technologies and innovative solutions and to realize an effective and person-centred health management along the complete care cycle (a *"continuum of care"*) through a seamless integration of clinical, at home and mobile healthcare services and a move from treatment of acute episodes to prevention [4],[5].

In currently applied healthcare practice, a disease is commonly discovered after symptoms have emerged. Only then, people become patients and apply for medical care; a diagnosis is made and a treatment is proposed and initiated. CHIRON fosters a shift towards an earlier diagnosis based on the risk assessment of the still healthy person. Detection and diagnosis are based on the analysis of heterogeneous medical data - originating from historic data, medical knowledge sources, imaging systems, collection of vital sign data by sensors and handheld devices - that are performed on a continuous base, anytime and anywhere. Medical doctors have remote access to the person's health record and are able to take a more proactive role in prevention of diseases.

This is a significant innovation compared to the currently used approaches that are based on health-related parameters only, often monitored *instantaneously* and *episodically* (during clinical center visits). In addition, the correlation across physiological, psycho-emotional, environmental parameters, as well as the use of relevant data derived from non-medical applications (such as a patient's physical activities or stress levels), contributes to innovations in the development and use of e-health systems. The CHIRON project defined a protocol and plans to execute an observational study aiming to identify the most relevant markers for predicting degenerative trends in congestive heart failures [2].

It is worthwhile to notice that such a correlation model does not exist in practice. Presently, diagnosis of a disease depends largely on the experience of the individual doctors. The typical models for diseases only predict mortality or morbidity in long term but never identify "when actually" the person is at risk.

2 The CHIRON Concepts

As an effective response to the challenges in healthcare, the CHIRON research work is in line with three main concepts:

a. The realization of a "continuum of care" i.e., addressing in an integrated approach health management at home, in the hospital and in a nomadic environment where health is addressed not as the management of episodic events but as a value the single person and the whole community have to build and to preserve;
b. A "person-centric approach" where the needs of the citizens, the medical professionals and the whole community are at the core of the design and the uniqueness of each user is fully recognized ("personalized healthcare") including the use of proactive computing in which embedded systems anticipate the needs of people, adapt themselves to context and take the required actions thus enriching quality of life and fostering independence;
c. A knowledge-based system integrating past and current data of each patient together with statistical data related to the whole community in a large, distributed repository that is secure, easy to be accessed by the authorized persons, easy to be interpreted and fully understood in spite of the massive and diversified quantity of contextual information.

All of them are pursued by realizing breakthrough innovation in relevant technological areas.

2.1 Care at Home and Everywhere ("Continuum of Care")

A continuous multi-parametric monitoring of physiological and psycho-emotional state, environmental parameters, patient activity and lifestyle related factors has been realized and the best compromise between unobtrusiveness and accuracy ("medical validity") of the gathered data was pursued in designing it.

Measurements provided by the close-to-the patient remote monitoring are incorporated into physiological models and fused with anatomical and functional information derived from MRI and 3D ultrasound data, from which organ-level models are built and updated.

All these data - integrated with those available in the Hospital Information System - contribute to the building of an evolving Patient Health Profile with the relevant health aspects of the user including medical history, habits, etc. and to the definition of a personalized and constantly updated risk assessment model (identified in CHIRON as *Alter Ego*).

Another important aspect of the CHIRON architecture is the seamless integration of the personal health platform with the clinical workflow and the integration of the personal and medical data gathered in a "non clinical setting" into the electronic health record of the patient. The standards adherence with regard to the exchange of the medical information (HL7 v.3), a reliable and secure patient data management are key issues. Semantic interoperability will be realized.

2.2 A Person-Centric Healthcare Management

CHIRON provides personalization in the delivery of the healthcare services. The "one size fits all" paradigm will no longer apply, especially when it comes to medicine. Personalization in medicine translates in personalized monitoring planning, personalized feedbacks and personalized therapeutic treatments. Personalization will also feature in a coaching system to help the patient to reduce immediate risk and improve long term recovery. In CHIRON patient is empowered and motivated to self-manage his wellbeing. This person-centric approach puts the needs of the citizens, the medical professionals and the whole community at the core of the CHIRON design.

A specific innovation of the project is the management of the user profile; it evolves and automatically adapts over time according to the user needs and to the changed context. Such a profile represents an evolving model of the relevant aspects related to the health of a user and provides a continuously up-to-date risk assessment of his health status. Indeed, the profile evolution is a key concept, as state-of-the-art projects foresee an intelligent system that represent the user profile, but that is updated by doctors, according to their knowledge of the user. The CHIRON model allows to bring local intelligence close to the user. It does not only represent patient data and history, but also contains algorithms and rules that allow comparing monitored data with the user expected behaviour, resulting in a local alarm system.

2.3 A Knowledge-Based Medicine - Support to the Doctors

Medicine is confronted by the "age of globalization": the movement of people all over the world along with societal and economical developments mean that medical professionals have to deal with new diseases, new symptoms and new contextual factors relevant to the health of the citizens, such as changed environments, new nutritional habits and lifestyles.To make a diagnosis, to define the most suited treatment for the patient, the physician needs to make use of a massive quantity of data, aggregated from different large data sets, interpreted and integrated with community related statistical data and past knowledge. Moreover he needs to take timely decisions.

All these data represent the outputs of multiple and heterogeneous devices and subsystems ubiquitously distributed: physiological signs and activity information are gathered through unobtrusive on-body sensors and are contextualized with environmental parameters measured by discrete devices; results of lab analyses including image-based examinations are available in the information systems and PACS systems of the clinical centres and hospitals, epidemiological / statistical datasets and past knowledge are dispersed everywhere all across the world and sometime organized and stored in various repositories. In CHIRON all of them will be integrated in a large, distributed repository that is secure, easily interpretable and accessible by authorized persons. This *Virtual Data Repository (VDR)* provides an effective support to the medical professionals for early diagnosis and personalized treatment planning.

A critical aspect CHIRON addresses is the effectiveness and the intuitiveness of the feedbacks the system provides to the medical professionals. The risk to be avoided is the overload of the doctor with a plethora of data. In CHIRON they are interpreted and translated into features; an ontological approach is used to retrieve information from multiple distributed content repositories and present it in a structured and aggregated manner giving the doctor an easy and powerful tool for immediate understanding of the status of the patient.

We are aware that technology cannot replace the experience of the medical doctors but can support them in taking the most appropriate and timely decision. In CHIRON the doctor remains the protagonist of the healthcare process and the only owner of the clinical decision.

3 The CHIRON Architecture

In the CHIRON architecture all the devices /subsystems generating, interpreting and storing data are embedded modules of an overall complex system; each of them has the computing and memory capabilities to execute a specific task for which the outputs of other sub-systems are needed. In this network of embedded systems Internet provides the communication infrastructure for the exchange of information among them and the weaknesses of Internet in terms of quality, reliability and real time interchange of the information are compensated by a higher autonomy and robustness of each of the modules of the system. Each block is capable of operating dependably even in the presence of network degradation or temporary failure and is able of executing a minimal, essential task autonomously (e.g. the prompt warning of the patient if a vital sign is above the allowed threshold or the activation of an emergency call in the case of a critical event).

These intelligent blocks – integrated all together – form a networked system with nodes distributed everywhere and all cooperating to realize a complex and important task , in our case the delivery of effective and high quality healthcare services to the citizens.

This is exactly the vision driving the European ARTEMIS JU Program i.e. a world in which smart "objects" have "a presence in cyber space, exploit the digital information and services around them, communicate with each other, with the environment and with people, and manage their resources autonomously" [3]. CHIRON intends to contribute to the realization of this vision in a so important and complex domain such as the healthcare one. Being the citizen and his quality of life at the core of the healthcare model proposed by CHIRON as well as of other processes involving the daily life of people, the CHIRON system – even if specifically designed for healthcare – interoperates across many application domains. CHIRON will use a middleware which will allow to achieve interoperability between heterogeneous devices and services, exchange of multisource information among the overall healthcare cycle and a multi-domain compatibility.

4 Innovation in CHIRON

The project promises to progress beyond state-of-the art in several disciplines such as healthcare architecture, sensor nodes with enhanced capabilities, new methods and algorithms for the measurement of physiological parameters, advanced solutions for the analysis and the visualization of medical images.

The technological challenges of this new Personal Health System fully integrated into the conventional hospital-based Healthcare System are in the realization of the best synergy among conflicting requirements such as data gathering and data processing in resource-constrained systems (the wireless mobile sensors network), unobtrusiveness of the monitoring combined with accuracy of the measured data, continuous monitoring vs. unobtrusiveness of the solution and its acceptance by the patients, automation or minimal human intervention vs. the reliability of the feedback, availability of a massive quantity of data vs. the easy and fast interpretation of these data by the medical professional, privacy and security of data vs. easy and ubiquitous access to these data by authorized persons, etc.

The advanced solution proposed by CHIRON represents a solid contribution to solve these issues. More specifically CHIRON will develop:

a. sensor nodes with enhanced capabilities (multi-parametric monitoring, local processing, energy harvesting and power management),
b. innovative methods for the measurement of biological parameters (ECG, blood pressure with enhanced accuracy, serum potassium concentration in the blood),
c. advanced solutions for the analysis and the visualization of medical images,
d. a dynamic and personalized risk assessment model (*Alter Ego*),
e. a distributed data storage approach (Patient's Virtual Data Repository) with enhanced data security and privacy provisions.

In the current age of image-centred medicine the new advanced tools developed in the CHIRON project are expected to facilitate real time processing, computer-aided detection and accurate visualization of medical image and to support doctors in making accurate diagnosis by reducing the risk of a "false negative" or the need for additional and costly examinations due to a "false positive".

Furthermore in contrast to the typical architectures employed in remote monitoring, in CHIRON sophisticated signal processing is done at the sensor nodes themselves with an emphasis on medically trustworthy parameter extraction in order to reduce the burden on the network and transmission energy. Separate optimization of signal processing algorithms and architecture cannot be applied here since this approach does not guarantee overall energy optimization. Thus a cooperative and holistic approach needs to be taken for increasing energy efficiency. Novel energy optimal algorithms and architectures leading to ultra low-energy ASIC realization for on-board signal denoising, artifact removal, intelligent classifier and feature extractor for each of the electrophysiology sensors without compromising the medically trustworthiness quality of the captured signals were realized.

5 Conclusions

The CHIRON research project contributes in promoting a new way of delivering healthcare services and promotes a paradigm shift from diagnosis and treatment of patients based on symptoms to diagnosis of patients based on risk assessment of healthy persons.

As a part of the observational study – planned during 2012 - the CHIRON project intends to execute a socio-economic assessment of the proposed solutions to check the "economic evidence" and the benefits in terms of better quality of care.

Moreover CHIRON intends to contribute to the uptake of a market still in its nascent phase, the e-health one, identified by the European Commission as a *"lead market"* where "innovative products / services / solutions have high growth potential, where EU industry can develop competitive advantage and where action by the public authorities to deal with regulatory obstacles is needed".

Acknowledgement. The CHIRON research programme has received funding from the ARTEMIS Joint Undertaking under grant agreement n° 100228 and from the National Authorities of Italy.

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User Adoption of Mobile Apps for Chronic Disease Management: A Case Study Based on myFitnessCompanion®

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Abstract. Health and Fitness apps for smart phones and tablets are changing the way we look after our health. This paper analyses the usage of such an app called myFitnessCompanion for chronic disease management. The analysis is based on data collected from 5000^{+} users over a period of 7 months. Highlights of the study show that blood glucose, weight and blood pressure are the main physiological data being monitored. Americans and Germans are the front-runners in adopting mobile health apps and are willing to pay for it. Most users choose to enter data manually instead of using automated wireless Bluetooth sensors. Users prefer to store the collected data on the phone rather than exporting it to Personal Health Record Systems.

Keywords: mobile health, Health and fitness apps, chronic disease management.

1 Introduction

Mobile Health apps are health and fitness related applications running on mobile devices such as smart phones and tablets. An increasing number of people use mobile apps to monitor their health or fitness and gradually they are being used for prevention, diagnosis and treatment. Mobile health apps are a step towards ubiquitous healthcare allowing chronic disease patients to self-manage their condition using mobile devices and wireless sensors.

Every day, new health apps are added to App stores such as Google Play or Apple's App Store. For free or a few dollars an app can be downloaded that helps the user losing weight, monitor their blood pressure or guide the user in their workout exercises. People from more than 190 countries download apps everyday and a total of 10 billion downloads have been recorded up to December 2011 [1].

According to the Global Mobile Health Market Report 2010-2015 [2], more than a third of the 1.4-billion smartphone users will use some kind of mobile healthcare application in 2015. At the time of writing (April 2012) more than one thousand health and fitness apps are on the Google Play [3]. Of those, 317 Apps use some sort of sensor (e.g. weight scale, blood pressure monitor, accelerometer, GPS) to collect

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data. 152 apps were found that use one or more wireless (Bluetooth/Wi-Fi) sensors which communicate with the mobile app to collect and transfer physiological data.

myFitnessCompanion®[4] is such an application developed for Android phones and tablets. It offers personalized exercise tracking and monitoring of weight, blood pressure, asthma, blood glucose, HbA1c, cholesterol, temperature, respiration, oxygen, intraocular pressure and heart rate using Bluetooth/Wi-Fi sensors or manual input. The therapy fields include fitness, diabetes, asthma, obesity and hypertension. Fig. 1 shows several screenshots of myFitnessCompanion on a smart phone.

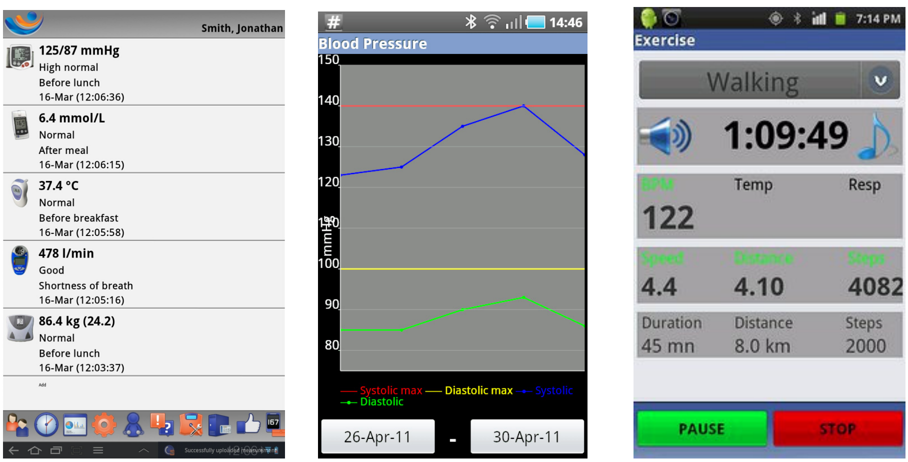

Fig. 1. myFitnessCompanion data and exercise tracking examples

myFitnessCompanion allows the user to keep track of their progress on easy to read graphs on the phone or to upload data to Personal Health Record (PHR) systems such as Microsoft HealthVault or Google Health[1]. Thresholds and targets for each physiological data monitor can be set to suit the user's particular condition and personalized feedback is given in text or voice after each measurement (See [4] for more details).

myFitnessCompanion was launched worldwide via Google Play in February 2011. The application can be fully tailored to 11 different languages (e.g. English, Chinese, French, Spanish) and no marketing campaign has been conducted for any particular country. The application uses Google Analytics [5] to collect anonymously usage data. Google Analytics is a very effective tool and offers detailed insight in the features used by myFitnessCompanion users. The results presented in this paper are based on Google Play statistics and Google Analytics data from 5000+ users collected between June 2011 and January 2012.

myFitnessCompanion offers 3 different versions of the app (Free, Silver and Gold). For the free version the number of concurrent physiological data monitoring is limited to 3 and 10 measurements can be stored before the user is asked to upgrade to the paid

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[1] As of 1 Jan 2012 Google Health has been disabled.

version (Silver or Gold) or to delete old measurements. The Silver version allows unlimited collection of measurements for three physiological data monitors. The Gold version is the premium version with no restrictions and allows also the upload of measurements to PHR systems. Due to the different versions some results presented in this paper are limited to users using the paid version of the app. The results are further limited to data collected from users that own an Android phone and voluntarily want to monitor their health.

The objective of this study is to gain insight into the level of maturity of the health and fitness App market for chronic disease management from a user's perspective. It wants to find out whether users are willing to use health and fitness apps such as myFitnessCompanion. It also investigates which conditions are being monitored and which functionalities of myFitnessCompanion are used.

This paper is organized as follows: Section 2 analyses the myFitnessCompanion demographics and focuses on languages used and country of origin. Section 3 investigates the type of physiological data tracked and how the data is entered into the application. Section 4 discusses how users prefer to store their data. Section 5 concludes with a brief SWOT analysis on the use of mobile apps for chronic disease management.

2 Demographics of myFitnessCompanion users

myFitnessCompanion has been installed by 5000+ users since it launched in February 2011. Initially the app was only available for mobile phones but due to the increasing popularity of tablets a trend is visible that users install myFitnessCompanion on tablets as well. Tablets are very well suited for users in need of larger screen sizes due to poorer eyesight. The statistics in Fig. 2 suggest that our typical user owns a mainstream mobile phone that is approx. 1 year old with not necessarily the latest OS installed.

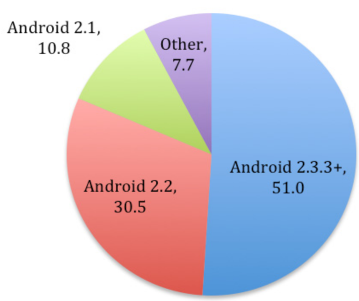

Fig. 2. Android OS breakdown (%, source: Google Play statistics)

Users can set instructions and feedback in their own language. Currently myFitnessCompanion supports English, Chinese, Spanish, French, Portuguese, Russian, Dutch, German, Korean, Brazilian and Italian. Fig 3 shows that English is the most widely used language followed by German and Spanish. It is surprising that the Chinese speaking countries seem not to use myFitnessCompanion. This is in stark contrast with a study conducted by MiniWatts Marketing Group [6] that puts Mandarin/Cantonese just behind English as the most used language on the Internet. The most likely explanation is that the Google Play is not available in China and therefore the exposure of myFitnessCompanion is very limited.

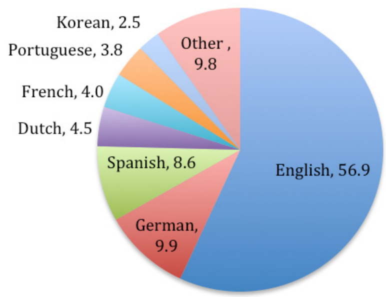

Fig. 3. Language breakdown (%, source: Google Play statistics)

When looking at the distribution of users per country (Fig 4), we find that four of the top ten most App savvy countries [1] use myFitnessCompanion: South Korea, the United States, Israel and the Netherlands. Surprisingly a quarter of myFitnessCompanion users (25%) live in Germany. However, this is in line with literature: A Deloitte's study [7] mentions that the German fitness market has reached a new record high in 2011 and Germany has 7100 fitness facilities with more than 7 million members registered, which is 8.9% of the total population. The report concluded that Germans put increased value on physical fitness and they are willing to spend money on it. Another article about the 75th anniversary of a German sporting medal designation [8] phrases it as follows: *"Kaum eine Nation besäuft sich derart an der eigenen Fitness wie die deutsche"*. Translated: "Hardly a nation gets so giddy (literally: drunk) on its own fitness like the Germans."

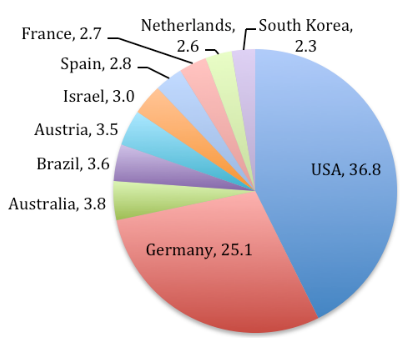

Fig. 4. Country breakdown (%, source: Google Analytics[5])

3 What Are myFitnessCompanion Users Monitoring and How?

myFitnessCompanion can collect and interpret physiological data based on user preferences and personal thresholds. It enables users to adjust thresholds and targets to suit their particular conditions and fitness levels. Users can also receive reminders to take their measurement and choose to receive text and voice feedback. During the study period, 40% of the total events recorded by Google Analytics for myFitnessCompanion where related to data monitoring.

Physiological Data Monitoring: Fig. 5 shows that users mainly monitor their blood pressure (28.5%), blood glucose (28.1%), weight (27%) and heart rate (5.5%). Only a small proportion of users monitor other physiologic data such as oxygen, asthma, respiration, HbA1c, cholesterol or temperature.

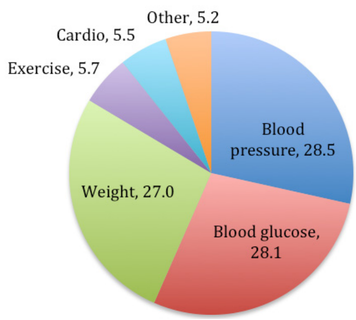

Fig. 5. Data monitoring (%, source: Google Analytics [5])

This is inline with feedback received from myFitnessCompanion users, which indicate that they also use complementary apps to monitor their diabetes, blood pressure and weight loss. Comments from users illustrate this observation as well:

> *"The app is serving me well, by allowing me to track my weight and heart rate which was very important to me."*

> *"Awesome! Works great with my Droid X. I use this mainly for getting body composition readings by Bluetooth connection to my scale (…)".*

Exercise Monitoring: 5.7% of the monitoring is related to exercise tracking. myFitnessCompanion can track different types of exercises using real-time monitoring of heart rate, body temperature and respiration rate. It uses built-in GPS for accurate outdoor distance tracking. The vast majority of users use the exercise functionality to monitor their walking exercise (70.2%). Other exercises are cycling (5.6%), weight training (4.7%), running/jogging (4.2%) and treadmill (3.3%). The following user feedback shows the use of the exercise feature:

> *"Excellent app for use with my* heart rate *Zephyr HxM monitor. App records monitor readings for my workouts and then I export the data for analysis of my training. I like the fact I can change the frequency the data is recorded for the different workouts. The connection with Google Health saves time by uploading data. Built in graph gives a quick glance at the overall data from a workout. The ability to get voice output of data during workout is helpful when I can't monitor the screen. Having a Bluetooth earpiece to listen makes it even more convenient. Great App!"*

Manual Data Entry Versus Wireless Sensors: myFitnessCompanion works seamlessly with fifteen different Bluetooth sensors and one Wi-Fi weight scale. The current list of hardware sensors supported can be found in [9]. The app also allows users to enter data manually. To date most users (88.6%) enter the data manually and only a small percentage uses one of the wireless sensors supported. A possible reason could be the complexity of pairing the Bluetooth sensor with the mobile device. However the app includes step-by-step videos showing how to pair a specific Bluetooth device [10] and this overcomes many potential difficulties based on user feedback received. The most likely reason is the substantially higher price of these Bluetooth devices compared to a non-Bluetooth device and also the fact that most users prefer to keep using their own medical devices.

On-demand Versus Continuous Monitoring: The majority of measurements are recorded on demand (94.5%) and only a small percentage monitor continuously their heart rate, respiration or oxygen level for a longer period of time. This is in line with the observation that myFitnessCompanion users mainly monitor their blood pressure, blood glucose and weight, which do not require continuous monitoring.

4 User Preferences for Storing and Sharing Health Data

myFitnessCompanion stores the recorded data locally on the phone but also allows the user to upload the data to a Personal Health Record (PHR) system such as Google Health or Microsoft HealthVault. This allows the user to share health records with health professionals, doctors, and research institutes.

PHR Servers. The vast majority of users keep the data stored on their phone (91,7%) and use the built in graph functionality to view their progress. Only 5.3% use myFitnessCompanion server and 3.1% uploads the data to Google Health. These low percentages are most likely related to the fact that users need to have the premium (paid) version of myFitnessCompanion to be able to upload data to PHR servers. With the recent addition of Microsoft HealthVault, we expect these numbers to go up.

File Export. myFitnessCompanion allows the export of physiological data in Excel format or graphs using email. Blood pressure (40%) is most used which can be explained that many users want to share their blood pressure history with their GP.

Furthermore, blood pressure and blood glucose are the most popular physiological data being monitored by myFitnessCompanion users. The export of exercise tracking data (11.7%) is relatively high due to the fact that these users want to monitor and compare their performance over time.

Export to Social Networking Sites. myFitnessCompanion allows users to post their measurement results to Facebook or Google+, which can improve their motivation. An example Facebook wall posting is shown below (Fig. 6).

Fig. 6. Facebook wall posting example

However, sharing health related data with social networks is not very popular. We identified two possible reasons: Most people affected by chronic disease are not willing to share this type of data with friends.

5 Discussion

We conclude this paper with a short SWOT analysis of the user adoption of mobile apps for chronic disease management based on literature research and experience with myFitnessCompanion.

Strengths: Health related apps on mobile devices are often easy to use and appeal to many users. It allows users to take measurements whenever they need to. The apps offer a lot of functionality for either free or a few dollars and health professionals start using the physiological data collected from these apps in their diagnosis. These apps are particularly suitable for chronic disease patients since they need to collect and monitor their health for a longer period of time independent of a specific location.

Usage data collected from myFitnessCompanion confirms this and we see an increasing interest by consumers. Particularly, Americans and Germans are early adopters and are willing to pay for these apps. Blood pressure, weight and blood glucose monitoring are most popular which relate to cardiovascular, diabetes and obesity diseases, which are the most prevalent in developed and developing countries [11].

Weaknesses: This study highlights that measurements recorded using mobile health apps are mainly entered manually by the user. This allows for inaccurate data entry, which could compromise its reliability. Self-motivation to record data over a longer period can be a challenge without the involvement of a health professional. Also, with the proliferation of mobile health apps, it is difficult for developers/companies to make it commercially viable and might result in poorer solutions or faulty apps if they are not integrated in a total end-to-end healthcare solution.

Threats: There are significant challenges ahead for mobile health apps due to proposed U.S. Food and Drug Administration (FDA) regulations [12]. A major problem with the current proposal is that it could stall the innovation of mobile health apps since it is almost impossible to obtain FDA approval fast enough to keep up with the continuous release of new smart phones, tablets or operating system updates. However, FDA involvement would remove health apps that make unwarranted medical claims.

Security and privacy concerns may prohibit the wide adoption due to concerns about data breach and misuse.

Opportunities: According to research from Frost & Sullivan [13] the mobile health application market will grow substantially of the next few years. The growing awareness of health and fitness apps in the medical community, as well as the growing proportion of patients using mobile devices will encourage healthcare professionals to exploit the possibilities rendered by smartphone technology and incorporate applications into their chronic disease patient management plans.

Overall, the outlook is positive and we believe mobile health applications will continue to grow as users and other healthcare stakeholders plan to adopt mobile technology. Mobile health Apps are a natural complementation of health telematics and personal health records. They should be part of a complete solution to address changes in healthcare delivery, and they are particularly suitable for chronic disease prevention and management.

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Effects of In-home Tele-Rehabilitation on Task Self-efficacy in Mobility Impaired Adults

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Abstract. A randomized controlled pre-post intervention study was undertaken to assess changes in task self-efficacy after a four-week intervention protocol. The intervention groups received once-weekly, one-hour therapy sessions targeting 3 mobility and 3 transfer tasks delivered either by Traditional In-Home Therapy or remote interactive Tele-Technology. Participants completed a 10-item, Likert scale measure of task self-efficacy at enrollment and after four weeks. Overall the intervention groups had a statistically significant increase in self-efficacy compared to the control. Comparisons between the two treatment delivery methods showed a medium standardized effect size (SES) in both groups compared to controls, although it did not reach statistical significance for the Tele group (SES Tele 0.35 [-2.5-.95]; Trad 0.54 [0.06-1.14]). Although further study is needed, this trend towards increased self-efficacy irrespective of the mode of rehabilitation delivery suggests that tele-rehabilitation can be a viable alternative to traditional in-home therapy.

Keywords: tele-rehabilitation, in-home therapy, remote therapy.

1 Introduction

Traditional in-home therapy provides the opportunity for rehabilitation to occur within the context of everyday task performance. Nonetheless, while in-home rehabilitation has generally been successful at preventing decline in activities of daily living (ADLs) [1] as well as facilitating recovery of ADL functioning and locomotion [2, 3], it is limited by cost, travel distance and lack of trained personnel. To overcome these limitations, relatively inexpensive video teleconferencing technology offers a practical alternative to traditional home visits for successfully treating ADL task performance deficits and increasing an individual's task self-efficacy (i.e., his/her confidence in performing salient functionally-oriented tasks required for successful day to day living).

Evidence suggests that self-efficacy is an important aspect of rehabilitation both in terms of a patient's propensity to engage in a rehabilitation program as well as in the outcomes of the program. First, a number of studies have shown that self-efficacy

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can enhance or impede rehabilitation efforts with older adults. These include participation in rehabilitation activities [2, 4] and exercise interventions [6]. Low self-efficacy has been found to be an independent predictor of disability and activity restriction, when controlling for health and functional status, physical disability, depression, hospitalization or institutionalization, falls risk and prevalence, [4, 5, 7-10]. Conversely, high self-efficacy has been associated with increased recovery from trauma, injury and newly acquired disabilities [11, 12].

Whereas several pilot studies have suggested that telerehabilition can enhance ADL function, no studies have examined the effects of in-home therapy delivered via tele-technology on self-efficacy. Moreover, previous tele-technology studies were limited to teaching individuals adaptive techniques. No studies had used tele-video technologies for delivering a comprehensive, multifactorial intervention similar to traditional in-home rehabilitation (i.e., functional exercise, assistive technologies, home modifications and adaptive techniques) was yet to be explored.

The purpose of this randomized clinical trial was to demonstrate that a comprehensive, 4 week in-home therapy intervention could effect a change in mobility self-efficacy among a group of mobility impaired adults, and secondarily to explore the effects of two different delivery modalities (i.e., remote therapist using tele-technology versus therapist on-site in the home). Such information is crucial for justifying home therapy as well as incorporating remote therapy via tele-technologies as part of home health services.

2 Methods

Community dwelling veterans of all ages with a prescription for a new mobility aid (i.e., walkers and wheelchairs) and who had not used the same type mobility aid for more than one month in the preceding year were randomized to either a Usual Care Group (UCG), which received no therapy as part of the study or one of two intervention groups that received the same four-week therapy intervention via tele-video (Tele Group) or traditional in-home visit from a therapist (Trad Group). Given the nature of the interactive nature of the intervention, neither the subjects nor the investigators were blinded to the intervention.

2.1 Intervention

Although a large body of work focusing on the effects of context-specific interventions is lacking, existing data suggest that exercise, assistive technology, and environmental interventions have a positive effect on safety and task performance, and that providing or prescribing these interventions in the home is equally or perhaps more effective than providing them outside the home. Overall, our literature review provided reasonable evidence that existing rehabilitation practices including prescription of individualized, functionally-based exercises, home hazard assessments, and home visits to train patients in the use of adaptive strategies were effective in the home setting. The literature review also supported the importance of real-time, improvisational interaction between the therapist and the patient. Thus, technological needs for remote delivery of rehabilitation in the home include observation of the patient while carrying out gross motor activities, observation of the patient carrying out functional activities in diverse locations, and real-time, two-way communication between the patient and the therapist.

Based on the existing literature, Participants in the 2 intervention groups received one-hour therapy sessions for four consecutive weeks. The intervention focused on 3 transfer tasks (bed, toilet, and tub/shower) and 3 mobility tasks (locomotion throughout the home, negotiation of the entrance and doorways within the home, mobility in the kitchen). The intervention included an exercise component and an adaptive strategy component. The *exercise* component of the intervention (e.g., stand-to-sit, hip and knee bends, bridging and buttock lifts) targeted underlying impairment at both the body structure/function and activity level domains while *adaptive strategies* targeted external contextual factors (reducing the demands and increasing the safety of the environment) to help compensate for extant disability. Based on the nature and number of problems identified during the baseline traditional home or tele-video visit, individualized “adaptive prescriptions” were scripted for each subject. These prescriptions included three types of interventions: adaptive techniques/methods (e.g., bed transfer training), assistive technologies designed to increase functional abilities (e.g., overhead or mobile lift, sliding board, commode chair), and recommendations for home modifications chosen to reduce environmental demands (e.g., add lighting, install grab bars). The exercises and adaptive prescriptions were similar to contemporary rehabilitation practices typical of home health care for patients with non-specific functional decline and/or impaired mobility.

2.2 Tele-Video Equipment

The tele-technology used in this clinical trial was developed for a previous study to provide remote home assessments [13, 14] and adapted for this project to allow direct patient-therapist interaction. The mobile, wireless tele-video system consisted of “off-the-shelf” technology that used plain old telephones system (POTS) lines to transmit real-time, two-way audio and video between the patient’s home and the therapist in a clinic and enabled the camera to move freely throughout the house without cables. A research assistant with similar expertise to a home health aid, who would be expected to operate the equipment when implemented as a clinical service, operated the equipment in the home.

The remote home video kit was designed to permit the therapist to have two-way audio communications with the project staff on-site in the subject’s home as well as two-way audio and video communication with the patient. For ease of transport, the remote kit weighs only 15 pounds and fit in a computer-sized case. The videophones are “plug n’ play,” designed to replace standard phones without additional installation costs. To facilitate observation throughout the entire home, the system uses wireless radio frequency (RF) to enable the portable, palm-sized video camera to move freely without wires and transmit real time images from anywhere in the home. The cameras operate at zero lux, which minimizes the effects of poor household lighting on the quality of the images transmitted to the therapists. A wireless headset allows the on-site project staff operating the camera to receive instructions from the therapist up to 150 feet from the videophone.

2.3 Outcome Measure

Although no validated task efficacy scale existed for mobility impaired adults, the Falls Efficacy Scale (FES) was a well-validated and reliable [15, 16] measure of confidence in completing 10 routine household mobility tasks. Individual items on the scale range from 1 “not confident at all” to 10 “completely confident” for each of the 10 activities: getting dressed and undressed, cleaning the house, preparing simple meals, bathing, shopping, going up and down stairs, reaching into cabinets or cupboards, getting in and out of a chair, walking around the neighborhood and hurrying to answer the phone. The FES focuses on frequent fallers by posing the question: “How confident are you in performing the following activities *without falling*? However, the 10 household tasks are equally applicable to any mobility-impaired population. To adapt the protocol for our study, the scale was modified by removing the words “*without falling*.” The question simply asked: “How confident are you in performing the following activities?” This provided a direct measure of confidence in perceived ability to perform the 10 tasks. Internal consistency (Chronbach’s Alpha) of the measure with the present sample was .91 for the 10 items.

2.4 Procedures

At the beginning and end of each session, the therapist interacted directly with the patient via headphone and the video camera. However, during the tasks themselves, even though the patient had continuous audio and visual access to the therapist, the technician was the primary person directing the patient through a task following the relevant protocols. Since the purpose of the study was to demonstrate efficacy of equipment to enable remote home therapy, this allowed the patient to concentrate on performing the task safely rather than being distracted by novel technology. The technician was in continuous communication with the therapist via earphones and head-mounted microphone, and the video camera. The therapist was able to view the patient's performance via the video camera and was able to hear all communication between the technician and patient. Depending on the assessment, the video camera was either placed on an appropriately located tripod or is hand carried by the technician as the subject progressed through specific functional tasks.

2.5 Data Analysis

Primary data collected at each site were entered into the Statistical Package for Social Sciences version 10 for analyses and verified by inspection, cleaning, along with double entry of approximately 10% of the data. Univariate descriptive statistics were computed to describe the groups at baseline and at the six-week follow-up. The chi-square test was used to determine the significance of differences for categorical variables, and the analysis of variance (ANOVA) F-test was used for continuous variables. To test the primary hypothesis repeated measures analysis of co-variance (ANCOVA) was used. The ANCOVA addressed the primary research question concerning group differences in task self-efficacy changes over time between the IG and the UCG. Standardized effect sizes (SES) and 95% confidence intervals (CI) for the average change in task self-efficacy were used to report the secondary exploratory comparisons between the Trad and Tele Groups.

3 Results

3.1 Sample Description

Randomization resulted in comparable distributions of all baseline patient characteristics for the UCG and IG. The sample reflects the veteran population from which the vast majority of subjects (90%) were drawn. Approximately 84% of the participants were male. The mean age was 62 years (range 42-86 years). Half of the sample (50%) were Caucasian, 45% were African American, 2% Hispanic and 2% American Indian. Over three-quarters of the patients reported earning a minimum of a high school diploma and 87% reported living with at least one other person. All of the subjects were able to walk independently or with assistance at least some of the time and the majority of subjects in both groups were using walkers. There were no significant differences in self-reported task difficulty levels or dependence on another person for help with the transfer and mobility tasks between the study groups. At baseline, no subjects were totally independent and all reported some difficulty in some of the tasks. There were no significant differences in average dependency or difficulty scores as a function of time or group (F=.458, P=.501).

3.2 Effects of Intervention on Self-efficacy

Effects of Intervention. At baseline there were no differences in task self-efficacy scores between the two groups. From baseline to post-intervention there was a significant change in self-efficacy (F=6.32, P=.015) that was manifest in an 8.7 point increase in self-efficacy scores in the IG (56.3 to 65.0), which was more than 7 times greater than the increase of 1.2 points (59.1 to 60.3) in the UCG. Further, there was a statistically significant group by time interaction (F=4.25, P=.044) suggesting that the change in self-efficacy is primarily attributable to the intervention.

Effects of the Intervention Modality on Self-efficacy. Table 1 shows results of exploratory analyses of the effect size related to the way that the intervention was delivered (Tele vs Trad visits). For both Tele and the Trad groups, the intervention had a medium effect size[41] (SES 0.35 in the Tele Group and 0.54 for the Trad Group), which reached statistical significance only in the Trad group. When effect sizes were examined as a percentile standing of the average intervention participant relative to the average control participant, both methods of intervention delivery had a very large change compared to the UCG. Specifically, at 6 weeks the self-efficacy standing of the average subject in the Tele Group and the Trad Group exceeded the average percentile standing of a subject in the UCG by 64% and 71%, respectively.

Table 1. Self-Efficacy score and the standardized effect size of Tele Group and Trad Group compared to Usual Care Group on change in Self-Efficacy

	Baseline *mean (SD) [95%CI]*	6 weeks *mean (SD) [95%CI]*	Change *mean (SD) [95%CI*	SES ± 95% CI	% tile
Tele (n=16)	55.2 (23.1) [42.9 – 67.5]	62.4 (20.9) (51.2-73.6]	7.2 (14.6) [-.6-14.9]	.346 [-.25-.95)	64
Trad (n=16)	57.4 (23.2) [45.0 – 69.7]	67.7 (21.8) [56.1-79.3]	10.3 (13.4) [3.2-17.5]	.540 [.06-1.14]	71

4 Conclusions

The study goal was to show that 4-week, in-home OT/PT could effect a change in mobility self-efficacy among a group of mobility impaired older adults, and secondarily to explore the effects of two different approaches to delivering the intervention - by a remote therapist using tele-technology versus a therapist physically present in the home. Overall, the effect of the intervention on mobility task self-efficacy was demonstrated by the significant differences between pre- and post-intervention scores at baseline and six weeks, respectively, for the IG compared to the UCG. Some of those differences can be attributed to natural recovery. However, improvement in self-efficacy in the UCG group should have been occurred through increasing familiarity with the new mobility device and any physician ordered therapy that they received. Nonetheless, the change scores in the IG were more than 7 times higher than the UCG at week 6, suggesting that a short, 4 week, comprehensive, multifactorial intervention of less than 1 hour duration per visit can positively influence task self-efficacy. These findings, together with those from prior studies not only support the need for individualized prescription of interventions, but also suggest that in-home training in the use of these interventions should be the standard of care whenever mobility aids, equipment and assistive technologies are prescribed.

The study also suggests that both televideo and traditional methods for providing in-home rehabilitation can be effective. While these analyses are only exploratory due to the small sample size in each group, they nonetheless have important implications for the delivery of in-home therapy. Travel time and distance pose significant challenges to provision of traditional in-home rehabilitation services. Local specialists capable of providing in-home care may be limited, particularly in rural areas, and the cost associated with practitioners traveling large distances typically restricts the provision of in-home services to relatively small geographic areas. Moreover, when in-home rehabilitation is provided, the continuity of care is often compromised because the therapist providing care is seldom the same individual who provided inpatient services. Televideo may help address this problem in several ways – as a clinical service, home health nurses could operate the technology to provide therapists with access to a patient in lieu of or prior to a home visit to increase efficiency and effectiveness of the visit; it could be used in consultation with providers who treated the patient in the hospital, improving coordination of care; and it could be used for cost-effective follow-up after an in-home visit.

5 Discussion

Despite the findings, the technology did have limitations that impacted the way remote rehabilitation can be delivered, if it can be delivered at all. First, the technical capabilities did not support the same type of audio and video communications between the therapist and patient that would be expected in an in-home, face-to-face intervention. These included: slow transmission speed of POTS lines that caused images to have visual lag time and some tiling due to movement, the restriction to one person being able to talk at a time, and the limited field of view through a camera lens.

To compensate for these limitations, a number of modifications were made to the protocol. First, to compensate for transmission delays and tiling images, the onsite technician had to be trained to describe patients' movements and to act as a go-between for all communications between the therapist and patient. This permitted real-time feedback to patients during functional activities. Second, was not possible to initiate a question or comment while someone else was talking, as one might do in normal conversation. As a result, communication was systematized by limiting each individual to 1-2 sentences followed by a verbal confirmation of communication receipt (e.g., "OK?"). Third, because the camera was focused on the patient, remote therapists only had visual access to the context in which tasks were completed. While this was adequate for observing transfer tasks confined to small areas of the home (e.g., toilet), it was inadequate for mobility tasks (e.g., getting in and out of the house) that were impacted by environmental features that were often out of view of the camera. To enable a remote therapist to have visual access to all areas of the home, just as he/she would in an in-home visit, procedures were changed to pan the camera within a space rather than simply train it on the patient engaging in the tasks. Nonetheless, although we were able to adjust our intervention procedures to compensate for the technological limitations the end result was that rehabilitation via tele-video technology is not simply a remote version of an in-home process.

Finally, the videophone technology itself is an issue. The study began several years ago when POTS-based phones were ubiquitous. However, the rapid demise of traditional landline telephones in the home suggests that providing in-home rehabilitation with POTS-based videophones may no longer be practical. While this could be good news for better transmission capabilities with the increasing use of smartphones and tablets, 4G smartphones are even more limited in their field of view and most tablets still utilize 3G networks that lack bandwidth and speed to enable real time observation of in-home activities. Whereas WI FI and 4G transmission are fast enough to enable observation of tasks, most homes do not have WIFI and the video capability of 4G smartphone cameras is inadequate. To overcome these limitations, one option that is being proposed in a new study is setting up set up a local WIFI network within the house using a 4G modem and a mobile broadband router. This should provide sufficient bandwidth within the home while enabling the video to be transmitted via 4G to a remote therapist. A second option will be a telepresence robot, which will not only provide 4G transmission, but will enable the remote therapist to control the camera and the robot's movements via the internet, this eliminating the need for an onsite technician to handle the camera. Whereas this alternative sounds tempting, the $6000 cost for a robot versus $150 for a router is substantial. If that is not a sufficient drawback, having someone available at the home to uncrate, charge and get the 17-pound robot up-and-going suggest that perhaps this technology is not ready for rehabilitation prime time.

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The Use of Telerehabilitation to Provide an Exercise Program to Improve Balance in a Post-stroke Population: Preliminary Results

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Abstract. This pilot study aimed to confirm the feasibility of dispensing a balance exercise program by telerehabilitation in a post-stroke population and to evaluate participants' satisfaction regarding the health care received. Four post-stroke participants were included. The intervention consisted of exercises inspired from Tai Chi movements, 45-minute sessions twice a week for 8 weeks. Fall-related clinical variables and health care satisfaction were assessed before, immediately after the intervention and two months later. Health care satisfaction was evaluated at the end of the intervention. All participants showed improvements for all of the variables measured: balance (Δ between 1-6/56), fear of falling (Δ between 3-17/60), motor function for the leg and postural control (Δ between 1 and 2 stage), functional gait (Δ between 11-47%), and lower limb strength (Δ between 20-43%). Satisfaction was also high. The result supports the feasibility of in-home Tai Chi teletreatment as a valuable alternative for some stroke patients.

Keywords: Balance, Telerehabilitation, Stroke, Fall prevention.

1 Background

The functional recuperation of a stroke depends on several factors including severity of the initial impairment, the capacity of spontaneous recuperation and early rehabilitation. Consequently, the mobility and balance of patients diminish, which leads to important risks of falls, an important chronic problem. Usually, rehabilitation is based on a treatment approach that begins during the stay in acute care, which is followed by an intensive functional rehabilitation program and is continued at home. However, in Canada, only 10 to 15% [1] of individuals have access to rehabilitation after a stroke because of the lack of services. Otherwise, literature supports the need to organize outpatient rehabilitation services for this population, regardless of the severity of the damage in order to prevent chronic problems and to reduce institutionalization [2]. In this context, telerehabilitation is a promising alternative to improve access to rehabilitation services [3].

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2 Literature Review

2.1 In-home Rehabilitation Following Stroke

Sensorimotor, cognitive and perceptual deficiencies result in balance and gait impairments, which enhance falls in post-stroke older adults [4]. However, balance is considered as one of the most promising reversible risk factor to reduce falls [5]. Recent studies have demonstrated that a re-education balance program based on Tai Chi movements improve balance in people at risk of falls [6]. A study carried out by Tousignant et al. [8,9] demonstrated similar results in frail older people. This randomized study showed that the fallers who received conventional physical therapy had a 1.3 greater risk of falling than those in the Tai Chi intervention group [8]. More interestingly, these re-education balance programs based on Tai Chi movements have also demonstrated their efficacy specifically in post-stroke older adults [10].

2.2 Teletreatment

Teletreatment is a series of therapeutic interventions on a long-term period between a health care professional and a user. In the case of the teletreatment offered from a service center to a user's home, a *first category* consisted of making available a virtual environment and/or a game console in a home, which is connected to a service center. Some rehabilitation studies are listed for a post-stroke population [11-15]. A *second category* consisted of dispensing a group exercise program for users at home or in a community center provided by health care professionals in a service center [16-18]. A *third category* consisted of physical therapy treatments over a long-term period given to a user at home by a health care professional from a service center. This kind of teletreatment has demonstrated trends of effectiveness on clinical outcomes in different populations: 1) older adults in loss of autonomy [19], 2) older adults living at home with mild to moderate dementia [20], 3) with mobility impairment [21] and 4) with total knee arthroplasty [22,23]. None of these studies has focused on teletreatment based on balance rehabilitation exercise programs in a stroke population.

3 Objectives

The general objective of this study was to evaluate the potential of using telerehabilitation from a service center to the stroke patient's home as an alternative to the rehabilitation service field in order to improve balance, and ultimately diminish falls.

The specific objectives were to: 1) obtain a first estimation of the efficacy of in-home telerehabilitation intervention with a post-stroke population, with mild to moderate balance problem, and 2) evaluate participants' satisfaction with the health care received.

4 Technological Infrastructure for Telerehabilitation

Based on experience from previous studies [22-24], the platform included various components designed to create a user-friendly experience for both the clinician and the patient at home. The core of these systems is the videoconferencing system (Tandberg 550 MXP), which uses a h.264 video codec, and integrates a pan-tilt-zoom (PTZ) wide angle camera and an omnidirectional microphone. The system was mounted over a 20-inch LCD screen, which displays the video received from the other end. Sessions were established using a high speed Internet connection over cable or DSL that was installed into the patient's home. The videoconferencing system used no more than 512 kbps. During the installation of the technology, training was given to the participant concerning the use of the platform. Up to now, this technological infrastructure has been used in varied rehabilitation programs: pulmonary rehabilitation, post-orthopaedic surgery rehabilitation, speech therapy exercises.

5 Methods

5.1 Design

The design used in this feasibility study is a pilot study with pre/post-intervention measurements with follow-up without a control group. Ideally, the efficacy of experimental interventions compared to standard interventions is evaluated by a randomized control trial. However, research in the physical therapy teletreatment field for a post-stroke population does not correspond to this level. We prefer to verify the plausibility effect in a post-stroke population with mild to moderate balance impairment who return home.

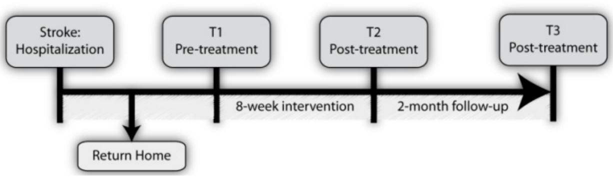

Fig. 1. Design of the study

Evaluations (T1, T2, and T3) lasted two hours and were conducted at the participants' home. The clinical outcomes measured were the same for each assessment, except for the participants' satisfaction about health care services which was collected only at T2. Independent evaluator from the intervention carried out all the assessments.

5.2 Participants' Recruitment

The target population was post-stroke individuals at least 50 years of age. Inclusion criteria were to: 1) had a stroke; 2) returned home after discharge from the hospital and have not received intensive rehabilitation; 3) presented balance problems; 4) have an available person during telerehabilitation sessions; and 5) have access to high speed internet at home. Exclusion criteria were to have: 1) severe corporal heminegligence; 2) significant visual impairment; and 3) non-controlled medical problems. Patients were recruited following discharge from the intensive stay at the hospital. A neurologist verified their eligibility. When a potential participant was identified, a research assistant presented the project. If the patient agreed, he/she was invited to sign a consent form, which was approved by the institution's ethics board.

5.3 Teletreatment Intervention

The intervention consisted of an exercise program based on Tai Chi dispensed by in-home telerehabilitation. The Tai Chi intervention consisted of a Tai Chi Chuan sequence and the movements were taken from the global sequence of Tai Chi [8]. A personalized approach was taken to adapt the movements to the participants' condition and to ensure their safety. Each session was planned to last 45 minutes twice a week for 8 weeks.

5.4 Outcomes and Instruments

The choice of clinical variables was determined according to what the literature demonstrated as known variables related to falls: balance (Berg) [25], motor function (Chedoke McMaster for the leg and postural control) [26], functional gait (Time Up and Go) [27], lower limb strength (Sit to Stand) [30], fear of falling (ABC-S) [31]. Patients' satisfaction with health care services was assessed with the French version of the "Health Care Satisfaction Questionnaire" [29].

6 Results

6.1 Description of the Sample

Four participants who suffered a stroke with mild to moderate balance impairment were recruited. Characteristics of the sample are described in Table 1.

Table 1. Participants' Characteristics

Characteristics	Participant 1	Participant 2	Participant 3	Participant 4
Gender	Man	Woman	Woman	Man
Age (years)	73	92	74	67
Rankin score	3	2	2	2
Post-CVA delay before 1st treatment (days)	30	25	18	21

Rankin 2 = light handicap; Rankin 3 = moderate handicap

6.2 Efficacy of the Teletreatment and Participants' Satisfaction

After an 8-week intervention, all participants showed a clinical improvement for all the fall-related variables. Hence, the score obtained for all questionnaires was greater after the intervention (see Fig 2), as well as the score of all physical tests (see Fig 3).

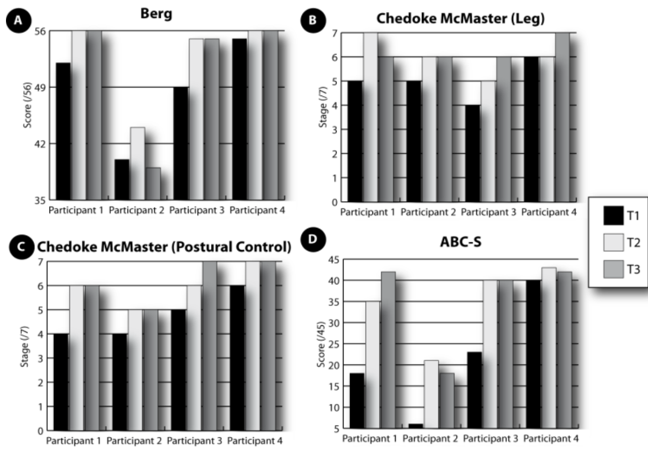

Fig. 2. Score obtained to balance (A), motor control (B, C) and fear of falling (D). T1: pre-test; T2: immediately after the end of the intervention; T3: two months after the end of the intervention.

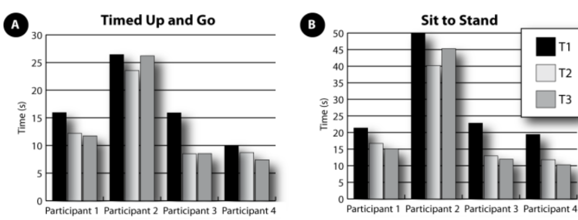

Fig. 3. Score obtained to functional gait (A) and strength (B). T1: pre-test; T2: immediately after the end of the intervention; T3: two months after the end of the intervention.

All participants showed improvements between 1 and 6 on the Berg scale, between 1 to 2 stages on the motor function of the leg except for participant 4 who remained at the same level (which was already high) and minimally at 1 stage for the postural control on the Chedoke score and up to 17/60 on the ABC-S score. Major clinical improvements were also demonstrated for the gait and lower limb strength recording less time to execute the task on the TUG and STS (11% to 47% and 20% to 45% less time, respectively). During the follow-up, the score on clinical variable stay the same or decrease lightly.

Participant satisfaction concerning the received health care was high. The score for the three factors measured was between 75% and 97%. For the questionnaire's global score, the participant's score were 82%, 80%, 84% and 91% respectively.

Furthermore, comments from the patients confirmed their satisfaction regarding their experience with the telerehabilitation: “It was easy [using the technology]. No, I didn’t find it difficult really. Actually, it was fun!” “There weren’t a lot of problems [with the Internet connection]. A few times we lost it for a few minutes, but it really gave us the advantage of traveling less and to have a personalised intervention.”

7 Discussion

Overall, our study gave a first indication of its clinical relevance. According to the results, an innovative in-home Tai Chi telerehabilitation appears to be a feasible and effective intervention method to provide rehabilitation in acute stage for post-stroke patients. The positive pre/post-intervention changes observed on balance, gait as well as motor function are good indicators, but only a randomized study will give information on the real efficacy of this intervention. Nevertheless, the stability of the clinical variable two months after the end of the intervention gives a first indication of the positive effect on the intervention instead on the only spontaneous recovery. Considering the importance to treat post-stroke patients in a short delay, this service approach offers the opportunity to increase the potential of functional recovery [30].

The high scores on the satisfaction questionnaire showed that these elderly patients appeared to accept this new service delivery method. After minimal training, all participants were able to function independently with the technology. This novel intervention method has the advantage to provide intervention to patients in their living environment without the need to move. This service is also a response to the lack of health care professionals by a reduction in their travel time in benefit of intervention time, which contributes to a better access to services. Nevertheless, this pilot study has some limitations. The participants were not randomly recruited. It is possible that the participants included in the study were more enthusiastic about modern technology and agreed more readily to participate. This could lead to a satisfaction bias. Furthermore, we need to realise a randomized study in order to be able to generalise the result. Moreover, the addition of a control group will allow investigating whether it was the use of the technology or the exercise regime that produce the improvements.

Concerning the telerehabilitation platform used in the study, observations made by the therapists and participants indicate that there is still room for improvement. By example, it will be more adequate for the therapist to demonstrate Tai Chi exercises by having additional cameras behind the therapist to improve the quality of the intervention.

In-home telerehabilitation seems to be a feasible and effective intervention method for post-stroke population. This services approach offers the opportunity to increase the potential of functional recovery for this population and then could prevent chronic problems like recurrent falls that lead to long-term institutionalization.

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Personalized Healthcare Self-management Using Social Persuasion

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Abstract. In this article we propose our framework for healthcare self-management that combines ubiquitous and social computing as persuasion media. The framework enables social interactions between the patients, doctors, and other users in their online social community through a web portal as well as through their smartphones. To help users in adopting healthy behavior, they are monitored for various activities and persuaded using different persuasion strategies that are adaptive and are according to user's behavior. Persuasion strategies are applied using persuasion profile of a user. A behavior model of each user is created that is based on Fogg's behavior model but also encompasses user preferences, health profile and social profile.

1 Introduction

Most of the recent research in healthcare management focuses on self-management of chronic diseases. Future environments are envisioned to be populated with computational technology that adapt to meet the needs of individual users. However, such technologies will be effective only if they can be utilized properly by the users. For this to happen, the networks, services and devices must be designed to be persuasive.

BJ Fogg defines persuasive technology as "any interactive computing system designed to change people's attitudes or behaviors" [1]. Persuasive technology has been used in healthcare management including self-management of chronic diseases. For this purpose, various persuasive strategies are devised that are applied to patients to increase their motivation or change their behavior.

When developing applications and frameworks for healthcare self-management, we must consider additional design requirements in addition to those required by normal application design [2]. First, the application should strive to encourage the user to change attitude or behavior toward healthcare management. Second,

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the application should help the user in determining and specifying healthcare-related goals as well as remind the user of achieving specific goals over time. Third, the application should support the user's objectives and goals by sharing relevant experiences from other persons in the user's social network; this includes user's family, friends, care takers, and doctors. In this article, we present our framework for persuasion in healthcare using social interactions. The interaction with the framework takes place via the most common social interaction platforms, namely, web and mobile devices.

The rest of the article is organized as follows. In Sect. 2, we provide an overview of recent work in persuasive healthcare. In Sect. 3, we present our framework for persuasive healthcare and in Sect. 4 we describe the persuasive strategies used by our framework. We then briefly describe our implementation in Sect. 5. We conclude this paper with description of future work in Sect. 6.

2 Related Work

In the domain of healthcare alone, persuasive technologies have been used for motivating healthier behavior using smartphones [3], for motivating elderly individuals to walk [4], for encouraging social and physical activities [5], for self-management of chronic diseases such as diabetes, stroke, Alzheimers, etc. [6].

Another important dimension is the social aspects of healthcare self-management. Due to recent popularity of social networking websites, researchers have found it very useful to use mass interpersonal persuasion strategies for promoting positive behavior in people of different age and gender and belonging to different cultures [7]. Thereafter, various researchers have used online Web- and social-media based strategies for persuasion. For example, using Web to support self-care of type 2 diabetes [8], preventing school dropouts using online media [9], and bringing web-based interventions for preventing alcohol and smoking [10]. Hence, persuasive technology based on social media is a very powerful tool for bringing about positive behavioral changes in individuals' lives.

Zhang et al. [11] has proposed a comprehensive healthcare infrastructure that include various context-based personalization services as well as a service interoperability platform. However, personalization does not include patient's history, expert's intervention or identification of patient's target behavior during recommendation, all of which are important aspects of our framework.

If we look these different approaches of assisting patients for healthcare self-management, we find emphasis on only monitoring the patient's data and then some pre-defined, generic feedback is sent to the patients. A patient is only advised in some traditional way and then it is left to the patient how to adopt these changes in daily life. Any automated system designed for patients should be able to identify a patient's lacking behavior and then it should include not only assistance but help patient motivate in that aspect. It is particularly this aspect that we have contributed in this article. Compared to the existing approaches, our social persuasion uses adaptive strategies that depend upon the user's context, preferences, and his profile. In the remaining article, we will show how these factors can lead to personalized healthcare self-management.

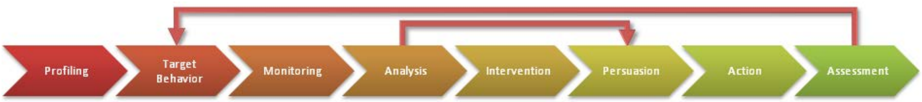


Fig. 1. Stages in the Intelligent Healthcare Self-Management

3 Framework for Persuasive Healthcare

The basis for our persuasive healthcare framework is monitoring-assessment model that consists of eight stages as shown in Fig. 1. Figure 2 shows the various components of the framework that roughly correspond to the different stages of the model shown in Fig. 1 and explained as following.

Context. For monitoring of user activities, we need to collect data regarding activities and behavior from the user on regular basis. In order to be able to learn about the user behavior and to reason on them, we need to know about the context in which an activity is performed. By context we mean any relevant information that can help us in determining the type of activity, the state of the user and the surrounding environment. Some of the context variables have been identified in Fig. 2.

Behavior Modeling. The behavior model of a user not only allows in understanding the user, but also helps in proposing him personalized recommendations and persuasive strategies for behavior change. The behavior model is built using user's preferences, health profile (including diet, exercise and physical activities) and their social profile. In the literature, a number of behavior theories and models have been defined, however, Fogg's behavior model [12] has been designed primarily for persuasive behavior design and, being a generic model, is also being used for behavior change in our framework. Fogg has identified three factors that are necessary for behavior change in his behavior model. These factors are: motivation, ability and triggers. Our behavior model uses these factors to devise the appropriate persuasive strategies for behavior change.

Social Interaction. A user's social profile is constructed from his interaction with other persons in his social network. These include family members, friends, colleagues, doctors, and other persons having shared interests with the user. Social interaction plays an important role in persuasive healthcare management. First, social interactions allow a patient to learn from experiences of other users (or patients). Second, the behavior of a person is determined and controlled significantly by others around them and his behavioral intentions are influenced by the social norms [13]. Third, social interactions can be very helpful in interpersonal persuasion [14]. That is why social interaction plays a constituent role in the user behavior model in our persuasion framework.

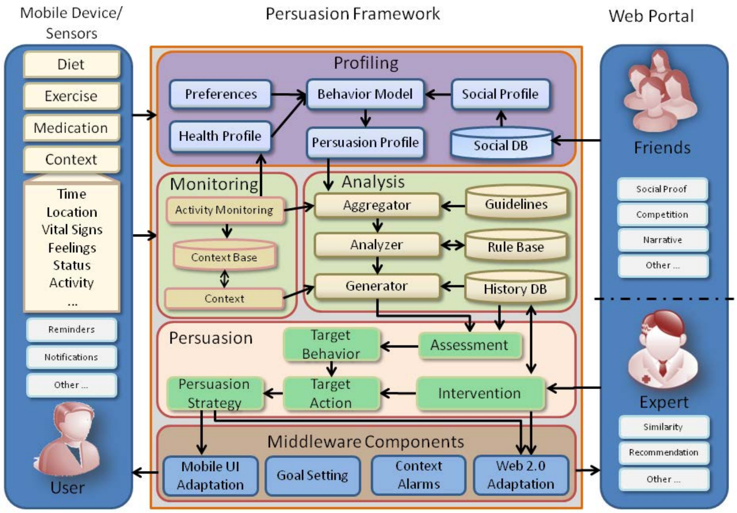


Fig. 2. The Framework for Intelligent Healthcare Self-Management

As shown in Fig. 2, users interact with the framework either through mobile devices or through a social portal. As we can see, mobile device is primarily used for data gathering related to user activities, but it can also be used to convey various persuasive strategies to the user for behavior change. The Web portal is more oriented towards social activities, but it is also a means for the user to learn from the experiences of others and for experts to analyze the user's data and to intervene on need-basis.

Rule-Based Analysis. Analysis in our framework is based on rule-based inferencing which is a method of generalized knowledge representation that deduces the proper result by expressing and selecting the knowledge in a way similar to that of human experts. The system can propose persuasive strategies only if it has the domain knowledge of a particular chronic disease (e.g., knowledge about diabetes). The domain knowledge is obtained from various clinical guidelines for healthcare defined by standard bodies such International Diabetes Federation (IDF). For the knowledge to be useful and consistent, it must be validated by the experts.

Expert's Intervention and Recommendations. Rules are defined by the experts (doctors). Without experts' input, the knowledge base cannot be maintained and verified. As our knowledge base evolves, new rules may be added or existing ones may need to be updated by the experts for consistency. For this purpose, experts are provided an interface for adding, updating or deleting rules. Thus, a suggestion to a user is actually the application of a rule previously defined by some doctor.

Persuasion Profile. Each patient can be persuaded in a way different than others. Persuasion profiling is used to track which mode of argument is most persuasive

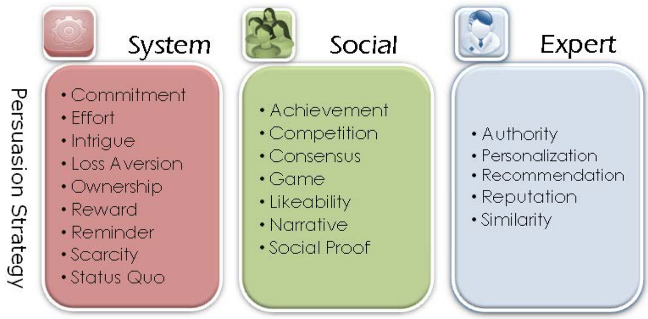


Fig. 3. Persuasion Strategies using System, Social network and Experts

for each person. A persuasion profile is unique to each user and depends on various factors such as user preferences, behavior model, social profile and target behavior. For some users, persuasion by experts is more beneficial while others are more persuaded by social means.

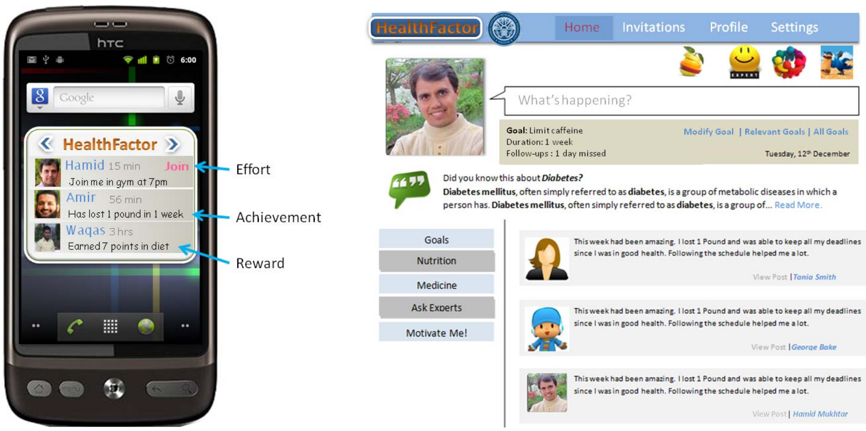
4 Persuasion Strategies

A persuasion strategy is used for matching target behaviors with solutions for achieving those behaviors. A number of generic persuasion strategies have been described in the literature, e.g., in [15][16]. Moreover, various specific persuasive strategies have been used by numerous researchers who have reported positive results in areas such as the management of smoking cessation, obesity, asthma, stress and insomnia [17], healthier eating [18] and directing users towards proper exercise behaviors [19] among others. All of these approaches target behavioral changes in the end-users through some persuasion strategies. Figure 3 describe some persuasion strategies and here we briefly outline how these strategies are used in different contexts.

4.1 Persuasion by the System

The persuasion profile of the user is used to propose strategies according to user's behavior and social profile considering their preferences and activities. The persuasion profile is combined with the context information and rules from the rule base to decide on the target behavior. The assessment of user's previous actions are also analyzed and taken into account before suggesting a target behavior. As shown in Fig. 2, a target behavior is translated into a target action for the user. A persuasion strategy is then designed that adapts the user interface accordingly.

Let's consider the example of the *commitment* strategy, which states that when a user commits to achieve a goal, he is motivated to carry out the related



(a) The application widget running on the home screen of phone and the different persuasive strategies used by the application

(b) The website for persuasive social interaction

Fig. 4. Mobile and web interfaces for social persuasion

activities. The system initiates commitment by helping the user to set goals. Similarly, the patient is also persuaded through *reminders* and context-based suggestions so activities can be performed with reduced *effort*.

4.2 Persuasion in Social Context

Encouraging activity through the social support of friends and family can be a powerful motivator to change behavior and inculcate healthy habits. Some persuasive strategies applied in the social context are as follows.

People like to hear stories from others. *Narrative* strategy is used to evoke the concept of sharing positive things with social contacts. This is also connected to the *achievement* strategy whereby describing an achievement, e.g., attaining a goal, excites the patient to do more. Similarly, an example of the *social proof* strategy is that the fact that most of the people in the social contacts perform regular exercise persuades the patient to start doing the exercise.

4.3 Persuasion by Experts

A recommendation by some official or *authority* weighs more than the one by friends or colleagues. Healthy tips and *recommendations* by doctors are shared with more prominence. Similarly, a doctor's recommendation is *personalized* according to the patient's profile, which gives him more confidence and motivation in achieving the goal.

5 Framework Implementation

Our implementation consists of a user-end smartphone application for the Android platform. The foremost persuasive strategy in the application design is that the application has been created as a service that runs inside an Android widget. Being a widget means that the user does not need to explicitly start the application to use it; nor the user needs to remember to use the application. This is because the application always remains on the home screen of the smartphone. It starts automatically and is brought onto the screen whenever the user unlocks the phone for making/receiving calls, sending/receiving SMS, and for checking emails or agenda. Being a service means that the application continuously monitors user activities and updates the user on regular basis about any notifications or events from the social network or experts. Figure 4(a) shows our application widget and the various persuasion strategies used by the application.

Figure 4(b) shows the social website through which the users interact with one another. The users can set their goal for behavior change or the system can propose some persuasive strategies for behavior changes. Similarly, users can view their health status as time-line along with the changes that occurred. Experiences from other users are shared in a persuasive mechanism via the previously described strategies.

6 Conclusions and Future Work

This paper focuses on the usage of two of the most widely used technologies – smartphones and social networks – as a tool for personalized healthcare management; particularly we considered the case for diabetic patients. Our framework combines the persuasive benefits of the worlds of ubiquitous and social computing to help patients and caregivers healthcare management. The smartphones are used to monitor the patients, collect the data, and help them in adopting healthy behavior through persuasion without the need of some relevant expert. Since social activities are equally important for a patient suffering from a disease or illness, our system also makes use of social computing for influencing users to achieve their goals. In this process doctor is also involved in analyzing patient's data and then suggesting and motivating them to cover the weaker aspect.

Currently, we have implemented our framework as an integration of our own Android-based mobile application and social portal. We aim to integrate our framework into existing social networking websites such as Facebook or patient-specific websites such as PatientsLikeMe (www.patientslikeme.com). Moreover, considering the huge amount of data that is generated from users' activities and that is to be processed by our system, we need to devise a scalable solution by deploying our system on a cloud platform.

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A Clinical Observational Study in the CHIRON Project: Rationale and Expected Results

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Abstract. Remote monitoring of congestive heart failure and acute coronary disease (CHF/ACD) using automated monitoring devices and bespoke care pathways/protocols to give early warning of deterioration and facilitate pre-emptive action may be an important solution to the dual problem of increasing healthcare need but static (or reducing) healthcare resource. The CHIRON pilot observational study (OS) tests use of novel monitoring technologies and integration of monitored data in a typical population of patients with CHF/ACD capable of being monitored remotely to either protocol-driven care informed monitoring. This is a European investigation of monitoring technology for patients with CHF/ACD. Differentiating aspects are: sophisticated and automated data collection in the context of protocol-driven care pathways, facilitating optimal management of CHF/ACD patients. The rationale for this OS is presented and why we believe that solid indications will ensue. The results will inform the design of a later powered multicenter study.

Keywords: Clinical observational study; Congestive heart failure; Monitoring technologies; Hospitalizations; CHIRON project.

1 Introduction

Important demographic and socio-economic challenges are facing present-day healthcare models: the ageing population suffering from chronic and cardiovascular diseases will require affordable "global" healthcare provided by fewer professionals and less medical infrastructure for critical, often mobile, patients. This will lead to a shift from reactive "health care" (how to treat patients) to preventive "health management" (how to keep people healthy). It is necessary to promote integrated system architectures to produce a "continuum of care" i.e. an integrated health management approach in which health is patient-centric in the home, in community and in the hospital. The challenge for such systems is to combine state-of-the art technologies and innovative solutions in an integrated framework designed for effective, person-centric health management throughout the complete care cycle. Recent efforts to achieve these in ends using monitoring technologies for congestive heart failure (CHF) have disappointed and costs were not reduced.

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We present a clinical observational study of the CHIRON project, its rationale and expected results and discuss how a later study powered for mortality/hospitalization endpoint could influence healthcare system re-designing telemetry for early event prediction to reduce hospitalization burden on both patients and healthcare systems in Europe.

2 The Rationale for the Study Protocol

No large randomised studies have evaluated the clinical or economic impact of care pathway-specific remote monitoring for management of CHF. However, pre-emptive remote monitoring by devices may enable earlier identification and treatment of pulmonary congestion and malignant arrhythmias (the two main mechanisms for mortality in CHF), which could reduce its morbidity and related hospitalization. Early detection of deterioration is enabled by implanted technologies that telemeter their recorded data for assessment by clinicians using bespoke information technology and which may offer greater benefit and better patient experience than available external technologies that patients themselves need to administer. There is now strong evidence from systematic reviews that remote (patient-driven) monitoring does reduce mortality, at least related to the few parameters investigated (going from ECG explored in no randomized clinical trial (RCT) to oxygen saturation and right ventricular pressure measured in 8-18% of cohort studies and arrhythmias and heart rate respectively looked for in 50 and 67% of cohort investigations with only weight and symptoms studied in all patients enrolled in RCT).

A recent meta-analysis by Klersy et al. identified 20 RCTs of remote monitoring for CHF (6,258 patients) and 12 cohort studies (2,354 patients). Thirteen only evaluated a telephone-based remote monitoring approach with 21 studying technology-based approaches, involving home monitoring equipment in 17 and an implantable device in 2. In all studies remote monitoring was associated with a significantly lower number of deaths (RCT: relative risk, RR, 0.83 $p=0.006$; cohort studies: RR: 0.53, $p<0.001$) and hospitalizations (RCT: RR: 0.93, $p=0.030$; cohort studies: RR: 0.52, $p<0.001$). Cohorts have significant larger effect sizes partly due to selection biases. In contrast, two recent external monitoring trials not included in the above reviews (HHH and HOME-HF Study) showed no reduction in death or hospitalization although emergency hospitalizations were reduced substantially. With improved CHF services (community-based nurse lead heart failure services and hospital-based specialist services) the picture is evolving. Of the 21 previous studies to have employed a technology-based remote monitoring approach, 17 used home monitoring equipment to collect physiological data such as blood pressure and weight, and another 2 used phone calls with decision support systems.

There is some evidence that other indexes should be looked for (as signs of impending decompensation) and particularly integration among parameters should be promising such as ST segment shift *with* heart rate changes and skin humidity as alluding to potential changes in sympathetic drive. These parameters, along with quality of life, cost and patient acceptability of remote monitoring have been less frequently reported. Clark et al.'s meta-analysis of remote monitoring trials found that of 14 RCT included, only 6 reported quality of life data, 4 reported costing, and 4 patient acceptability and none investigated integrated measures of potentially increasing sympathetic drive. There is therefore a need to further explore the remote monitoring field. It is a particular challenge to evaluate whether monitoring of established and novel variables have greater predictive power, sensitivity and specificity when monitored both in combination and continuously.

3 Invasive versus Noninvasive Variables for CHF Monitoring

Implantable monitoring devices have been designed to measure many complex internal physiological variables. Adamson et al. investigated the use of an implantable monitor that provided continuous right ventricular (RV) haemodynamic data, in 32 patients with chronic heart failure. During the study there were 12 hospitalizations with decompensated CHF, and significant alterations in RV haemodynamics were detectable prior to 9 of these episodes, 4±2 days before hospitalization. Using the same device in a randomized controlled trial, Bourge et al. evaluated a remote monitoring strategy for 274 patients with CHF. There was a non-significant reduction of 21% in CHF related events in the remote monitoring group, with a significant 36% ($p=0.03$) reduction in CHF related hospitalization. Yu et al. retrospectively evaluated an implantable system capable of intrathoracic impedance monitoring in 33 patients with advanced heart failure. During the study 10 patients were hospitalized for fluid overload a total of 25 times. Over an average of 18.3±10.1 days prior to admission, intrathoracic impedance decreased by an average of 12.3±5.3% ($p<0.001$). Using an automated detection algorithm, an impedance drop below a threshold level was 76.9% sensitive in detecting hospitalization for fluid overload, with 1.5 false-positive (threshold crossing without hospitalization) detections per patient-year of follow-up.

It is notable that previous studies of technology-based remote monitoring care pathways have focused on haemodynamic assessments to predict deterioration, but arrhythmias also have a significant impact on mortality, morbidity and hospitalization rates. Sudden cardiac death, predominantly secondary to ventricular arrhythmias, is the commonest mode of cardiac death in all but the most advanced heart failure. Atrial fibrillation is present in around a third of patients hospitalized with CHF and adversely impacts on prognosis. Furthermore, in 48,612 patients enrolled in the OPTIMIZE-HF study, arrhythmias contributed to 13.5% of CHF hospitalizations. It is therefore likely that remote monitoring which evaluates arrhythmia burden as well as haemodynamics, as included in our clinical observational study, will improve outcomes when compared to monitoring of haemodynamic data alone.

The PARTNERS HF study showed that monthly review of CHF diagnostic data in devices could identify patients at higher risk of CHF hospitalization within the following month and suggests that algorithm-driven care of patients as planned in the principal study to follow our feasibility study is likely to be effective. However, this study did not address the issue of whether interventions driven by risk identification could reduce patient hospitalization. The RAPID RF study is intended to identify how remote monitoring can alter CHF management but uses only one monitoring technology and no bespoke remote monitoring care pathways.

Studies such as REM-HF, TIM-HF, TELE-HF, DOT-HF, SENSE-HF, EMPHASIS-HF, RAFT, Tele-HF and ASCEND-HF are currently investigating the use of implanted technologies in a very high risk CHF population, using CRT-D and ICD devices and are uniformly disappointing in the clinical benefit achieved by remote monitoring technologies. All failed to address optimal use of technologies in care pathway design opening up the possibility that noninvasive close-to-the patient monitoring might have at least a more favorable profile, provided its acceptability is assessed and costs are not increased.

4 The Variables Selected for the CHIRON Observational Study

There has been a great effort to select the parameters to monitor in CHIRON project since previous investigations concentrated on only a few of the candidate predictors. Parameter selection was made by a 2-stage process. First a Literature search was performed and a list of parameters was made available. There were more than 60 variables selected to include clinical, angiographic, biological, pharmacological, local ambient and electrocardio-graphic items which were considered in previous published investigations in CHF patients and were deemed relevant as potential short- or long-term risk factors for complications including hospitalization or mortality. A medical expert (reference) initially subdivided all selected variables into baseline information (for which an agreement apparently exists on the capability of potential long-term predicting value) versus short- or very short-term potential predictors. The same medical expert ranked all these variables by giving a synthetic probabilistic value to each potential risk factor, allocating a reliability code: L= low, M=average; H= high.

The second step was to perform a survey among European Opinion Leaders (EOL) in Cardiology as a means to obtain a comparative evaluation of the value of the selected variables. A questionnaire was constructed and the EOL were asked to reply the questions by giving a semi-parametric coded series of responses to specific questions. There were 32 EOL Respondents from Italy, Slovenia, Spain and United Kingdom. The results are presented in terms of average (±standard errors) and minimum and maximum per question.

Questionnaire First Part: Questionable clinical elements not enough proved by previous studies. Respondents have provided a probabilistic judgment of the reliability coded by the reference medical expert in step 1 by assigning coded responses from 1 (0 to 20%) to 5 (81 to 100% probabilistic association with risk) to questions subdivided to very short-term (Table 1) or short-term (Table 2) risks:

Table 1. Questions (n=14) to European Opinion Leaders on very short-term questionable clinical risk elements in CHF patients

Questions *VERY SHORT-TERM (hours to days) RISK*	Mean Responses	SE	Min	Max
Male gender increases the risk	1.88	0.17	1	4
The lower systolic blood pressure, the higher the risk	3.40	0.25	1	5
The higher LV mass the higher the risk	3.36	0.20	2	5
The lower financial income, the higher the risk	2.84	0.26	1	5
The lower the education level, the higher the risk	3.08	0.23	1	5
The lower serum sodium levels, the higher the risk	4.20	0.22	1	5
Higher hemoglobin increases the risk	1.64	0.18	1	4
The higher percent lymphocytes, the lower the risk	1.72	0.20	1	4
The higher CRP levels, the higher the risk	3.28	0.20	1	5
The higher fibrinogen levels, the higher the risk	2.88	0.17	2	5
When digoxin treatment is on, the risk is lower	2.24	0.27	1	5
When nitrates treatment is on, the risk is lower	2.08	0.22	1	4
When anticoagulant treatment is on, the risk is lower	2.24	0.20	1	4
When allopurinol treatment is on, the risk is lower	1.84	0.21	1	4

Table 2. Questions (n=11) to European Opinion Leaders on short-term questionable clinical risk elements in CHF patients

Questions (When…) *SHORT-TERM (weeks to months) RISK*	Mean Responses	SE	Min	Max
body weight increases rapidly, the risk is higher	4.16	0.23	1	5
in-house movements are reduced, the risk is higher	3.88	0.17	2	5
sweat increases, the risk is higher	2.76	0.23	1	5
skin temperature is lower, the risk is higher	3.04	0.26	1	5
the room temperature is higher, the risk is higher	2.28	0.23	1	5
room humidity is higher, the risk is higher	2.24	0.20	1	5
room air pollution is higher, the risk is higher	2.32	0.23	1	5
QRS duration increases, the risk is higher	3.84	0.14	2	5
T wave amplitude decreases, the risk is higher	2.36	0.22	1	5
R wave amplitude increases, the risk is higher	2.08	0.20	1	5
ECG-derived Serum potassium concentration level	-	-	-	-
(ECG-derived) may help defining increased risk	2.92	0.25	1	5

Questionnaire Second Part: clinical elements documented and/or more confidently assessed by previous studies are shown in Table 3. Respondents judged the correctness of the evidence condensed by the reference medical expert in step 1 by coded replies (0= False; 1= True) to the potential association between the described elements and their capacity to influence long-term risk in CHF patients.

Table 3. Questions (n=41) to European Opinion Leaders on long-term assessment of clinical risk elements in CHF patients

Elements in the Questions *LONG-TERM (several months to years) RISK*	**Mean Responses**	**SE**	**Min**	**Max**
Age	0.96	0.04	0	1
Body mass index	0.72	0.09	0	1
Weight	0.96	0.04	0	1
Waist-to-hip ratio	0.76	0.08	0	1
Diastolic blood pressure	0.84	0.07	0	1
NYHA class	1.00	-	1	1
CHF etiology	0.60	0.10	0	1
Left ventricular ejection fraction	0.84	0.07	0	1
Current smoker	0.92	0.06	0	1
Single/divorced	0.56	0.10	0	1
Physical activity	0.96	0.04	0	1
Oxygen saturation	0.84	0.07	0	1
Uric acid	0.64	0.10	0	1
Total cholesterol	0.56	0.10	0	1
LDL cholesterol	0.64	0.10	0	1
HDL cholesterol	0.76	0.09	0	1
Fasting glucose	0.84	0.07	0	1
Creatinine clearance	0.84	0.07	0	1
ST segment shift	0.72	0.09	0	1
Q wave	0.64	0.10	0	1
Left ventricular hypertrophy	0.96	0.04	0	1
Arrhythmias	0.96	0.04	0	1
Diabetes	1.00	-	1	1
Hypertension	0.88	0.07	0	1
Previous acute myocardial infarction	0.88	0.07	0	1
Chronic obstructive pulmonary disease	0.92	0.06	0	1
Peripheral vascular disease	0.96	0.04	0	1
Cerebrovascular disease	1.00	-	1	1
ACE inhibitors	0.96	0.04	0	1
Angiotensin Blockers	0.92	0.06	0	1
Beta blockers	1.00	-	1	1
Spironolactone	0.96	0.04	0	1
Statin	0.60	0.10	0	1
Amiodarone	0.44	0.10	0	1
Furosemide equivalents	0.88	0.07	0	1
Biventricular pacing	0.88	0.07	0	1
Intracardiac defibrillator	0.88	0.07	0	1
Both devices	0.88	0.07	0	1
PR interval	0.52	0.10	0	1
QT interval	0.96	0.04	0	1
RR interval	0.80	0.08	0	1

In the responses to the Questionnaires there was, in general, a good agreement between the initial coding made by the reference medical expert and the Respondents, although several discrepancies were noted. When the concordance analysis (in the probabilistic assessment of risk) was made, the following overall results were obtained: Concordance 38 (58%); Underestimation 9 (14%); Overestimation 19 (28%). Nevertheless, it was decided to consider and measure all the above mentioned 66 variables in the clinical observational study, making CHIRON protocol one of the more extended investigations performed thus far in CHF patients.

5 The CHIRON Observational Study Protocol

This study will test working practices related to application of CHIRON monitoring technologies and processes in CHF/ACD patients that will test applicability in the home setting, patient acceptance and clinical utility to inform design of a later major study powered to show mortality/hospitalization impact. The study is peculiar in that it monitors newly envisaged parameters (among them humidity, both on skin and ambient, patient movements and derived potassium levels) in addition to more standard ones such as ECG whose interpretation is however receiving a fresh look in both time and frequency domains. These parameters are closely interplayed since one major issue is integration to look for very short signals of outcome in monitored patients.

Risk-Benefit Justification: There is no increased risk to patients, as they will have access to currently available care pathways. However, the study will evaluate the acceptability of such monitoring to patients and their perception of this and any adverse impact on quality of life.

Study Hypothesis and Objective: We hypothesise that CHIRON monitoring technology managing CHF/ACD in the home, will have no adverse effects on patient quality of life and will indicate potential for improved and cost effective clinical outcomes. To evaluate patient and carer satisfaction of CHIRON monitoring devices for CHF/ACD management.To determine potential cost-effectiveness of CHIRON management devices. To evaluate very short time risk of outcome in CHF monitored patients.

Inclusion and Exclusion Criteria: Participants will all have CHF NYHA III and will have had a recent (within 3 months) hospitalization for CHF or be judged to be at high risk of repeat ACD events after admission to a coronary care facility within 6 weeks of enrolment. In addition, patients should meet all of the following criteria:1) Be on stable medical therapy for CHF for 6 weeks prior to recruitment; 2) Will have the ability to independently comprehend and complete Quality of Life Questionnaires; 3) Will have the ability to give informed consent; 4) Will be on optimal medical therapy according to the treating physician, working to NICE Guidelines. Participants will be excluded from the study if they meet any of the following criteria: 1) Unable to wear or use the technology due to mental or physical limitations or unfitness; 2) Less than 18 years old; 3) Pregnancy; 4) On a heart transplant list; 5) Life expectancy of less than one year (non cardiovascular related) in the opinion of the treating physician; 6) Currently have a “active” therapy device or monitor implanted. Recruitment will be by a letter of invitation (Ethics approved), attendance at outpatient clinics and in patients. Informed consent will be obtained by a study trained member of research staff and will include consent to inform GP and primary care team. There will be 100 patients recruited between 2 University Centers in United Kingdom and Italy. Recruitment is between March to May 2012; follow-up data analysis and reports: September to December 2013.

Study Details, Data Collection, Model and Costs: The purpose of the study is to collect monitored data from high risk, event rich population and to then correlate that data with CHF events. Building on the experience of the PARTNERS HF study, to determine the appropriate combined CHF device diagnostic threshold criteria for identifying prospective risk of worsening CHF, an algorithm based on the parameters measured by the CHIRON architecture which includes electrocardiographic parameters, patient activity, temperature, sweating, respiratory rate, and imaging. All monitored data will be entered into a bespoke electronic clinical case record form that will be accessed via the internet. This will be done weekly. In addition to remote monitor data we will employ the CHIRON architecture to ensure inclusion of imaging data in the risk model computational processes. Follow-up will be for a minimum of 9 months. Standard clinical evaluations will occur at 3, 6, and 12 months after enrolment. At each follow-up visit, the following information will be collected: NYHA functional classification, and patient cardiovascular medications.

The primary end point will be the number of CHF hospitalizations with pulmonary congestion, and the secondary end point the number of CHF health care utilization events, defined as unscheduled office visits, urgent care visits, emergency department visits, or hospitalization, with pulmonary congestion. Throughout the study, data on all cardiovascular-related adverse events and deaths will be collected. All adverse events and deaths will be independently adjudicated by the Steering Committee which will classify each adverse event as cardiovascular or not, and adjudicate an event as CHF related only if it has resulted in worsening CHF.

All participants will complete the SF-12EuroQol (EQ5D) and Kansas Heart Failure Cardiomyopathy Questionnaire (KHFQ) at enrolment, 3 months, 6 months, 9 months. Cost-effectiveness will be assessed using cost of interventions, cost of cardiovascular related health care use, and quality adjusted life years (QALYs).

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Does Location Help Daily Activity Recognition?

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Abstract. Daily activity recognition is essential to enable smart elderly care services and the recognition accuracy affects much the quality of the elderly care system. Although a lot of work has been done to recognize elderly people's activities of daily life (ADL), few systems have investigated if the location information can be deployed to improve the ADL recognition accuracy. In this paper, we intend to incorporate the location information in the activity recognition algorithm and see if it can help to improve the recognition accuracy. We propose two ways to bring the location information into the picture: one way is to bring location in the feature level, the other way is to utilize it to filter irrelevant sensor readings. Intensive experiments have been conducted to show that bringing location information into the activity recognition algorithm in both ways can help to improve the recognition rate by around 5% on average compared to the system neglecting the location information.

1 Introduction

Elderly people's activities of daily life (ADL) are important user context in smart home for elderly people. These activities include eating, getting in and out of bed, using the toilet, bathing or showering, dressing, using the telephone, and preparing meals. When such activities are accurately recognized, proper services can be provided accordingly [8]. Thanks to the rapid development of ubiquitous sensors (RFID, accelerometers,pressure, wearable sensors and etc.) and the data mining techniques, many daily activities can be recognized through analysing sensing data [9][7][10][12][4].

AQUEDUC project [1] is aiming to provide services to elderly people who live independently in the smart home environment. One common service is remainder service. And it can be provided at different levels. For example, when fall activity is detected, the relevant caregivers should be reminded as soon as possible. When abnormal sleeping pattern is observed about elders, the caregivers can be provided afterwards. Out of all the reminder services, the basic requirement is to recognize different activities of elders. The recognition of daily activity is a procedure to interpret low-level raw captured data to infer high-level context. Until now, lots of work has been done to recognize daily activities for elderly people. However, so far few papers have taken location information into consideration [2](the location in the paper refers to sub-areas in a smart home,

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Fig. 1. RFID reader in the wrist (left); Tags (middle); Receiver (right)

such as kitchen, living room, etc. Hereafter we will alternatively use sub-area and location). In the paper we would like to investigate if the users' location in smart home can be used to improve the accuracy and to what extent.

Basically, there are two broad categories of algorithms that have been proposed to recognize daily activities, one is rule-based, the other is machine learning based. The rule-based approaches explore experts knowledge in the form of "*if-then*" rules, which usually do not require training samples to infer context (activities) [11]. These approaches will fail if too many sensors and activities are involved [11]. The machine learning based algorithms learn models from training samples after feature representation and extraction [2][11]. One main drawback is that they usually require to label the training samples [7][8], which is quite tedious when the data set is huge. Among all the previous work, few of them pay attention to bring location information in [2]. In this paper, we focus on studying two ways of bringing the location information into recognizing the daily activity for elderly people. One way is to add the location information as one additional feature dimension while the other way is to utilize it to filter out irrelevant sensing readings. Considering the possible sequential relationship among different activities during a short time, we further filter out unreasonable recognition results and obtain even higher accuracy.

We will begin with presenting our activity recognition based smart system in Section 2, and followed by the recognition approach elaborated in Section 3. Then we will introduce the scenarios, and experimental results in Second 4. Finally, we present concluding remarks in Section 5.

2 An Activity Recognition Based Smart Elderly Care System

AQUEDUC [1] is an activity recognition based smart elderly care system, which contains 10 daily activities for elderly people, varying from dressing to making meals. Table 1 shows the list of the studied daily activities in the project, including their names and respected IDs. These 10 activities can happen in 4 sub-areas in the smart home. Table 2 provides the possible ADLs associated with each subarea. Please note certain activities can occur in different sub-areas, for example, elderly people can drink coffee in both kitchen and living-room. And elderly people can use the same objects for different activities, and move with them across different sub-areas. For instance, making meals and eating may happen in the kitchen and live-room, and they share the same dishes, bowls.

Table 1. Studied daily activities and their IDs

1	2	3	4	5
dressing	toileting	making calls	drinking	eating
6	7	8	9	10
washing hand	brushing teeth	watching TV	sleeping	making meals

Table 2. Information of activities and occurring sub-areas

Sub-areas (ID)	Daily activities
Kitchen (1)	making meals, drinking
Bedroom (2)	sleeping, dressing
Living-room (3)	watching TV, making calls, drinking, eating
Washing-room (4)	washing hand, brushing teeth, toileting

In order to recognize these daily activities, we deploy two types of pervasive sensors in the smart home, one is the simple switch sensor and the other is RFID sensor. Switch sensor can record two states of any home appliance, such as TV and telephone. RFID sensor contains a reader and many tags. When elderly people wear the reader in their wrists and the tags are attached on different objects, the RFID sensor can detect what objects elderly people has touched in sequence. Fig. 1 shows the pictures of RFID reader, tag, and receiver respectively. In this project, we have deployed 35 tags attaching to various objects (cup, bowl, toothbrush, etc.). When elders touch any object, the sensing data will be automatically transferred to a server wirelessly. The format of the each RFID sensing data log is shown in Table 3. It tells which object has been touched at what time.

Table 3. Data format

Action ID	Time	Tag ID
4	[2009-4-29 19:21:27.203823]	E00700001E0E7B0A

3 Activity Recognition Based on SVM

3.1 Feature Extraction

Features can be represented as $f = (s_1, s_2, \cdots, s_m)$, where m is the total number of sensors deployed in the smart home. In this project, we have deployed 35 RFID sensors and 2 switch sensors, thus $m = 37$. s_i records interaction times of elderly people touch the respected object for RFID sensor while it is 1 (ON) or 0 (OFF) for switch sensors at a given time duration(w). We get the first sample when receiving the first data log, and the second sample is obtained after α ($w = \alpha$) time . For each sample, Num_{min} means the minimal value

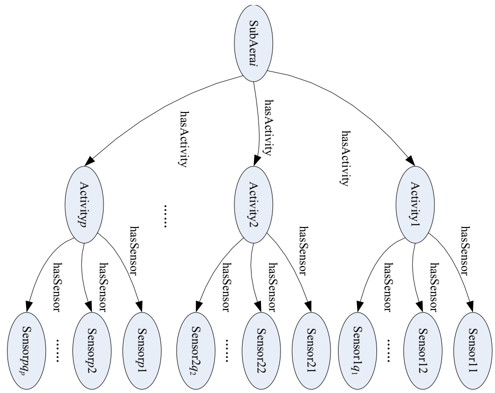


Fig. 2. Illustration of sub-areas, activites and sensors

across all the dimension, while Num_{max} means the maximal value. After that, we normalize the feature using the following equation:

$$s'_i = \begin{cases} \frac{s_i - Num_{min}}{Num_{max} - Num_{min}} \ (i = 1, 2, \cdots, m) & \text{if } Num_{max} \neq Num_{min} \\ 1 & \text{otherwise} \end{cases} \quad (1)$$

We have two ways to add the sub-area information into the samples. The direct way is to append on the end of the normalized feature as an additional dimension. And the feature is $f = (f, loc)$, where loc is the integer number respected to different sub-areas (can be seen in Table 2), varying from 1 to 4. The length of feature for each sample is 1 more than the number of sensors. Another way is to filter out the irrelevant sensor readings using the sub-area information. For instance, when elderly people were in the kitchen, though switch sensor recorded the TV "ON" signal, we still set the value on the respected dimension of f to be zero for the sample. This way is to filter out the irrelevant single, and only perform feature extraction for sensors in the sub-area where activity is taken place (see Eq. 2). After that, we normalize the extracted feature using Eq. 1. The dimension of feature for each sample is exactly the same as the number of sensors.

$$s_i = \begin{cases} s_i & \text{if } \textit{sub-area hasSensor } i \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

As can be seen from Fig. 2, for each sub-area, we can get its *SensorSet*. In a sub-area, it has many activities, and *hasActivtivity* illustrates the activities can be happened in the sub-area, and *hasSensor* shows the related sensors for the specific activity.The sensor set in the sub-area is the union of all the evolved sensors of all the activities which are taken place in the sub-area:

$$SensorSet\{Activity1\} \cup SensorSet\{Activity2\} \cdots \cup SensorSet\{Activityj\}$$

$SensorSet\{Activityi\} \cap SensorSet\{Activityj\}$ can be not empty, which means different activities can share same sensors. And also *SensorSet* of different sub-areas can have the same sensors, as some objects can be moved by the elderly people. For details of the methods of locating the elderly people in a smart home, please refer to [6][5].

3.2 ADLs Recognition Based on SVM

We input the samples got by proposed approach to the SVM classifier [3], and to see the performance. All samples are fed into the SVM with linear kernel function and the parameter is set to be $c\_set = [-3, -1, 1, 3, 5, 7, 9, 11], c = 2^{c\_set(k)}$. We denote the first way to add an additional dimension in the feature as LOA-SVM1, and denote the second way as LOA-SVM2. We also denote the baseline as SVM, which does not consider the location information. We perform feature extraction for all the samples from 5 persons, and label each sample. We use samples from one person as the test set, and another person as the validate set, while use samples from the remaining three persons as the train set. We show this procedure in Algorithm 1.

Algorithm 1. Procedure of evaluation

1: **for** $i = 1$ to 5 **do**
2: $test\_person = i$
3: $validate\_person = mod(i + 1, 5)//mod(a, b)$ gets the modulus of a divides b
4: $train\_person = rest$
5: **end for**

For ith test, we first get models of different c value using samples from $train\_person$, and then choose the c value which achieves the best accuracy in the $validate\_person$. Finally, we use the trained model with the selected best c value to see the performance for the $test\_person$. Overall accuracy (see Eq. 3) is used to evaluate the recognition performance. $Accuracy(i, j)(i \in \{1, 2, 3, 4, 5\})$ denotes the overall accuracy of ith experiment for $Activityj, j \in \{1, 2, \cdots, 10\}$.

$$Accuracy(i, j) = \frac{NumOfCorrect(i, j)}{TotalNum(i, j)} \tag{3}$$

where $NumOfCorrect(i, j)$ represents the number of samples that corrected recognized as j, while $TotalNum(i, j)$ is the number of samples which are labelled as j. The average overall accuracy which is defined in Eq. 4. It evaluates the performance across all the 5 test sets. We do not differentiate the test users in the evaluation.

$$Accuracy(j) = \frac{\sum_{i=1}^{5} NumofCorrect(i, j)}{\sum_{i=1}^{5} TotalNum(i, j)} \tag{4}$$

A common characteristic of activities is that people seldom change activities in a short time, especially for elderly people. This would help us to further improve the performance as the mention approaches assign a label to each sample, and

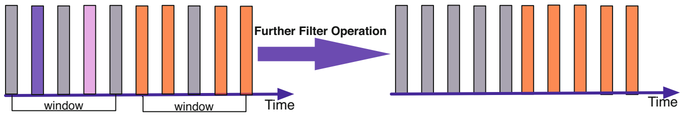


Fig. 3. Illustration of further filtering operation

do not consider the consistence of samples in time dimension. For example, SVM recognizes continuous 5 samples $\langle f_1, f_2, f_3, f_4, f_5 \rangle$ as

$$\langle r_1 = dressing, r_2 = dressing, r_3 = sleeping, r_4 = dressing, r_5 = dressing \rangle.$$

When people doing dressing, RFID read in the wrist may also read tags on pillow and the bed, resulting in the third sample is wrongly recognized as *sleeping*. However, we can simply deny the third sample as *sleeping* based on the characteristic of elderly people. We further fuse the recognition results in the decision level for every n continuous samples. n is set to be 5, which means we fuse every 5 samples which is shown in Fig. 3 (it is about 10∼15 seconds in real case). LibSVM [3] assigns a mass to a sample which represents the possibility of belonging to each activity A_i. Assume we have m activities to recognize. The output for each sample is $\overrightarrow{R}(f) = (p(A_1), p(A_2), \cdots, p(A_m))$. The final result of every n samples is obtained by the following formula:

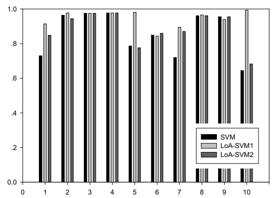
$$j = argmax \sum_{i=1}^{n} p_i(A_j) \tag{5}$$

4 Empirical Evaluation

In the project, we asked 5 elderly people to perform all the 10 daily activities in the smart home. We also design the following two scenarios in the experiment with the expectation of evaluating the effectiveness of the added sub-area information.

– *Scenarios 1: we sample drinking activity both in two sub-areas (kitchen and live room), as the activity can both take place in these two sub-areas.*
– *Scenarios 2: we turn on the TV when elderly people brush teeth in washing room to simulate the case they forget to turn off TV in the living room, and also hang on the telephone when they dress their close in bedroom.*

We first compare the results of SVM, LOA-SVM1, and LOA-SVM2 to verify whether the information of location can improve the accuracy or not. As can be seen in Fig. 4, at least one of them achieves higher accuracy for each studied daily activity, which clearly proves the effectiveness of exploration the location information. SVM achieves the accuracy up to 90% for making calls, drinking, watching TV, toileting and sleeping. However, for brushing teeth, making meals, and eating activities, the accuracy is low for SVM. For brushing teeth



	1	2	3	4	5	6	7	8	9	10	Accuracy
1	**233**	0	0	0	0	0	0	0	22	0	91.37%
2	0	**210**	0	0	0	0	5	0	0	0	97.67%
3	0	0	**313**	8	0	0	0	0	0	0	97.51%
4	0	0	0	**342**	0	0	0	0	0	8	97.71%
5	0	0	0	7	**358**	0	0	0	0	0	98.08%
6	0	4	0	0	0	**162**	26	0	0	0	84.38%
7	0	0	0	0	0	41	**348**	0	0	0	89.46%
8	0	0	0	0	0	8	0	**222**	0	0	96.52%
9	11	0	0	2	0	0	0	0	**186**	0	93.94%
10	0	0	0	0	2	0	0	0	0	**313**	99.37%

Fig. 4. Performance of three different methods. Accuracy (left); Confuse matrix of LOA-SVM1 (right).

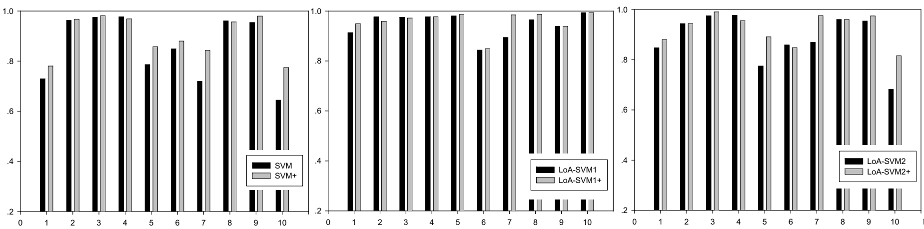


Fig. 5. Accuracy comparison results

activity, the reason is that the TV is always ON, which disqualifies the performance, and for making meals and eating, those two activities share many common feature. LOA-SVM1 performs much better than LOA-SVM2 for recognizing making meals and eating. With the additional location information in the feature dimension, LOA-SVM1 can well tell them apart as making meals takes place in kitchen while eating is in the living room. But for LOA-SVM2, it uses the location information to filter out the irrelevant sensors, and these two activity has the same $SensorSet$. All of three method cannot well distinguish washing hand and brushing teeth, and their accuracy are all below 90%. This is because no matter people wash hand or brush teeth, they will use the water from water faucet and dry their hand using the tissue. And these two activities both happens in the same sub-area. Although we explore location information, it will be helpless. We can see the confusion matrix of LOA-SVM1 for further proof (highlighted in the red circle in confusion matrix in Fig.4).

We also investigate the performance of three approaches with further filter every n samples, and we show the comparison result in Fig.5, where "+" denotes the respected further filter approach. From the figures, we can see that "+" approach can consistently improve the recognition accuracy for all activities, meaning the effectiveness of further filtering. The accuracy of dressing, brushing teeth, eating and making meals is greatly improved when comparing SVM to SVM+. LOA-SVM1+ also greatly improve the accuracy of recognizing brushing teeth activity (Activity 7), though a little increment of accuracy of washing hand. LOA-SVM2+ improves the accuracy of washing hand, making meals and eating dramatically and a little increment of brushing teeth. To sum up, with further filter technique, it can improve the recognition accuracy of activities which can not be distinguished by simply adding the location information in the feature dimension (such as washing hand and brushing teeth) and activities which share the same *SensorSet* (such as eating and making meals).

5 Conclusion

In this paper, we study if users' location information can improve the accuracy of recognizing daily activities for elderly people and to what extent it can improve. Concretely, we proposed two ways to incorporate the location information in. One way is to add it in the feature dimension directly while another way is to represent the feature only using the data from sub-area to filter "*noisy*" readings. We have shown two combined approaches can achieve upto 5% on average higher than results without adding the location information.

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A Robot-Environment Cooperation Architecture for the Safety of Elderly People at Home

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Abstract. The communicating objects of ambient environment can play a "facilitator" role in helping the assistive robot for locating itself, searching for a person... Conversely, the robot can be seen as a communicating object which is used by services to the person in loss of autonomy. We describe an architecture for cooperation between the robot and the ambient environment composed of sensors or actuators. One of the difficulties is that the robot is evolving in a crowded and not predictable physical environment. It is therefore necessary to have mechanisms of adaptation for answering to various or unforeseen situations so that the robot can move reliably in the home. It is necessary also to take into account two constraints, at first the degree of urgency of the service and secondly the degree of discomfort caused by the presence of a robot which is able to act near the person and see the person in her/his privacy.

Keywords: Ambient robotics, assistive robotics, cooperation architecture, adaptation to the context, multi-agent system.

1 Introduction

The meeting of ambient intelligence and assistive robotics gave birth to ambient assistive robotics which aims at assisting a person in loss of autonomy. It relies on the existence of a network of communicating objects present in the environment of the person. The objective is to propose a set of services and teleservices for facilitating the person daily life. One or more robots can be present in this environment. While previous generation of robots have been designed to perform specific tasks and built as independent units, the new generation of robots tries to take advantage of ubiquity. In this framework, the robot autonomy is obtained by a close interaction between the robot and the ambient environment.

Up to recent years the robot moved in a rather hostile environment which did not facilitate its task. In the context of ambient intelligence, the communicating objects of ambient environment can play a "facilitator" role in helping the robot for locating itself or for searching for a person... Conversely, the robot itself can be seen as a communicating object which can be used by services to the person in loss of autonomy. Several projects have been interested in combining ICT, mainly home automation and robotics, for the safety of the patient at home. The robot is started up after an automatic alarm or a voluntary call of the patient. The robot is either remote

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controlled by a distant user or moves autonomously. According to the projects, other services are added to the safety task such as stimulation task, technical assistance or social link. The RoboCare project initiated by the ISTC (Institute for Cognitive Science and Technology) [1] aims to make the elderly independence and quality of life at home by integrating different technologies. The objective of the project is to find the best ways to combine the caregivers and technologies which incorporate one or more robots, so that all act in a framework of harmonious cooperation for the service of the person. The IDorm project [2] is designed to assess an ambient environment composed of three categories of communicating objects: static objects associated with the building, a robot and mobile devices. IDorm architecture consists of a multiagent system that manages the operation of all the environment sensors and the robot. The sensors are controlled by an agent and the robot by another agent. The sensor agent receives the different measures from sensors and controls actuators which are linked to sensors such as a pan-tilt camera which is both a sensor and an actuator. The robot agent robot acts as a data server and coordinates exchanges of information between the user and the robot. It controls the navigation of the robot by combining different functions such as the obstacle avoidance or the search for targets.

The context of the work presented in this paper is the project ANR TecSan project QuoVADis [3] [4] [5] which aims at assisting a person in loss of autonomy at home. It concerns either the elderly or people with specific disabilities. The robot participates to the remote monitoring. In case of an alarming situation, the fusion of data from a device worn by the person on one hand and the sensor network of the ambient environment on the other hand, provides an alarm. The robot starts up for searching the person and then providing an audiovisual contact with a distant care giver. That way, the distant care giver is able to remove the doubt of a false alarm, to make clear the diagnostic and to choice the best answer to the alarming situation. It is important to note that the embedded device monitors the physiological parameters and the activity of the person. The scenario has been determined in cooperation with the remote monitoring center SAMU-92, which depends on AP-HP (Assistance Publique-Hôpitaux de Paris). Three cases have been identified related to the way of activating the robot: i) a volunteer call, ii) an alarm call and an erroneous call.

As said before, the services that the robot can bring to the user are directly related to the effectiveness of the robot mobility in the environment. The paper presents, on the one hand the general structure of the architecture which allows a co-operation between the robot and the ambient environment and, on the other hand the principles of adaptation which makes the system able to answer to varied situations. Indeed, the adaptation is essential for the robot is a physical object which can encounter unforeseen situations while moving in a real and cluttered environment. In order to avoid failures, the system must propose palliative solutions even at the cost of a degraded result.

The second section describes the cooperation architecture which is composed of two main components, the base of knowledge founded on the ambient assistance field and the multi agent system (MAS) which takes in charge the dynamic and heterogeneous nature of the ambient environment. The third section describes the principles which underlie the adaptive mechanism based on the coalitions of agents.

2 Cooperation Architecture

The system architecture must respond to two objectives. The first one is to facilitate cooperation between the robot and the ambient environment. The second objective is to contribute to the adaptation to the context. This architecture consists of two main modules that are the base of knowledge and the knowledge processing module that provides a response to a service request. Figure 1 represents the overall structure of the architecture. The ambient environment includes the communicating objects and the robot. The knowledge base contains persistent information used by the system such as house data or communicating objects features. A gateway is required for formatting and homogenizing exchanges between the system and the ambient environment. Indeed communicating objects and robots are provided by various manufacturers which use quite different exchange protocols.

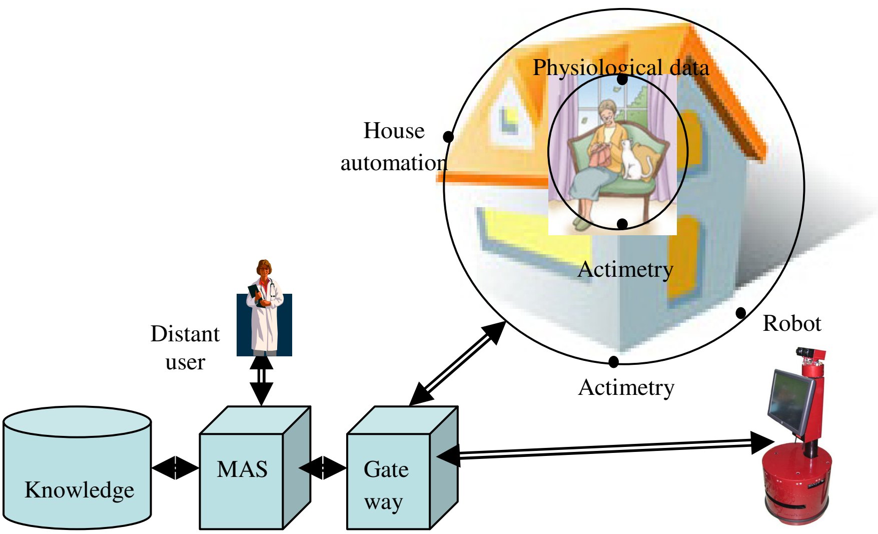

Fig. 1. Cooperation architecture

The MAS is the decision-making part of the architecture. It receives and acts on the ambient environment through the gateway. To make its decisions, the MAS uses data of the knowledge base implemented in the form of an ontology. The distant user can request a service or supervise the task performed by the system.

2.1 Knowledge Base

Information handled by the system is classified into two types. The so-called persistent information, related to the application domain, puts together data about the structure of the residence, the features of communicating objects. These static data may be updated. The second type concerns volatile data mainly the measures provided by the sensors and the orders sent to actuators. The information types are handled differently. The volatile data are distributed in each agent of MAS as explained later. The persistent data are centralized in an ontological database. They are used by the processing module for modeling and handling the resources of the ambient environment and carrying out the requested services. Four categories of information related to the application domain have been included in the ontology database: The *Home* category for defining the structure of the environment, the *Communicating object* category for knowing their characteristics and their operating mode, The *User* category for defining the user profile and the *Task* category that puts together the tasks and services that the system is able to achieve. These categories define the four concepts of the ontology (fig 2).

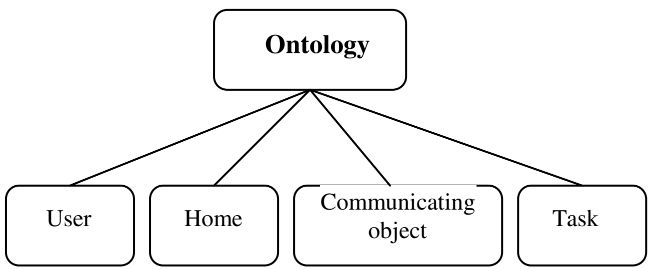

Fig. 2. Ontology

The ontology [6], [7] is representing the information of the base of knowledge in form of concepts. Ontological properties are useful for creating links between concepts or adding attributes to a concept. There are reliable software tools for creating and managing ontology. Another advantage is that a based-domain ontology can be shared and updated by the research community. Currently, there are few examples in the field of ambient robotics. In the following, we only describe Home and Communicating object sub-ontologies, the two concepts necessary for understanding the adaptation mechanism explained in the section 3.

2.1.1 Ontological Properties

The system needs to set up links between members of the same concept such as a topological relationship between two parts of the residence. Links are also needed between members of different concepts. For example, for processing a measure provided by a sensor, the system must locate the sensor in the residence. These links are referred to as ontological properties. We have defined three types of properties: relationship, use and attribute. The ontological property *relationship* defines a logical relationship, generally of owner relationship, which links concept members one another. The ontological property *use* defines the function of an object. This property specifies whether an agent can use the object to answer a service request. The ontological property *attribute* refers to the features of a concept or an individual concept member of the ontology. It specifies the operating mode of the object.

2.1.2 Communicating object Concept

The communicating object concept lists all sensors and actuators that are distributed in patient home. The objects are specified with three types of ontological properties. As said before, the first ontological property *use* identifies the object use. The information is handled by agents for determining whether they could be involved in answering a service request. For example, a presence detector can take part in the robot localization. Accordingly, robot localization is a *use* ontological property of this sensor. The operating features of communicating objects are specified by a set of ontological properties called *attributes*. This knowledge is treated by agents to correctly operate ambient objects. Finally, a third ontological property is useful for creating relationships with other concepts of the ontology. For example, for locating static sensors in the environment, we have defined an owner relationship between sensor and component of the residence.

2.1.3 Home Concept

The Home concept is representing the patient residence by a topological model that mainly describes the relationship between the components of the residence. This simple representation can be enriched by ontological properties such as attribute type. The model is capable of accepting a growing complexity according to needs. The basic topological model gives links between residence parts, walls and features such as doors or windows. The granularity can be increased by determining areas in a room according to the position of the sensors or markers placed in the environment. If necessary and if information is available, geometrical attributes (position, orientation) can be added to particular components of the model.

2.1.4 Interest of the *relationship* Property

The topological distance is defined as the number of hops between two individuals of the ontology. The hops are relations as defined above in the ontology. If the structure of the ontology is defined by a graph, the topological distance is the number of nodes which separate two individuals minus one. If I_i and I_j are any two nodes of the graph, dist(I_i, I_j) is the function to calculate the topological distance between I_i and I_j. If n is the number of nodes between the two individuals i and j, then the distance is: $dist(I_i, I_j) = n - 1$. The topological distance will be used by agents of MAS for robot localisation.

2.2 Processing Module Based on MAS

The processing module takes into account the data from the ambient environment, and adaptively treats data for generating a result close to the requested service. The processing module is based on a multiagent system [8], [9] which allows a distributed resolution of a problem. It consists in several hybrid agents. Each ambient agent encapsulates a communicating object such as a sensor or an actuator. Figure 3 represents the internal structure of an ambient agent. An ambient agent consists in three main components that are the input, the decision making and the output. The decision making module takes in charge the agent adaption and reactivity by using three main parameters that are *neighbourhood*, *history*, and *ability*. The neighbourhood parameter sets the list of agents that are close to this agent at a given time. The list contains all the agents, close to this agent and able to be involved in the response to a service request. The history parameter stores previous events and data which could be useful for better performing current task. At last, the ability parameter identifies the skill of the agent.

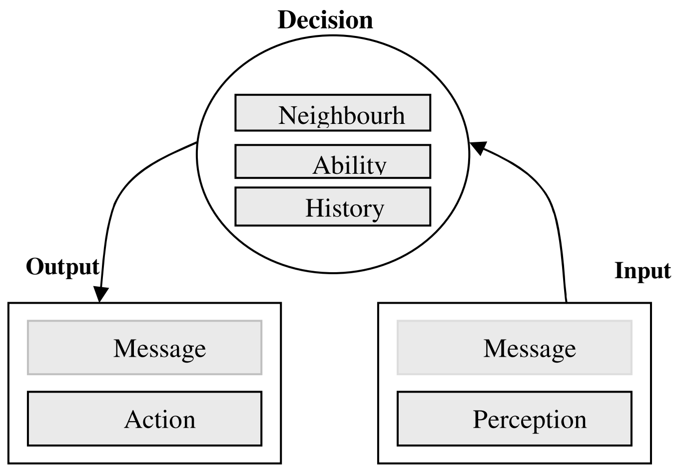

Fig. 3. Internal structure of an ambient agent

3 Adaptation Mechanism

The processing module starts up the search for a solution when receiving a service request. In fact, we have introduced a more general notion than service notion which we have called *effect*. An effect may be for instance a particular lighting at a precise place of the residence or for another instance the location of a robot or even a specific service to the person. The MAS configures itself for providing a solution according to the availability of the communicating objects in respect with criteria. Note that the goal is not to find the optimal solution but a solution close enough to the required effect. The adaptation to the context is inherent to the multiagent modelling, strengthened by coalitions and negotiation mechanisms.

3.1 Coalition Formation Protocol

The robot-environmental cooperation protocol is a set of rules that the MAS follows to obtain an effect. The Protocol is mainly based on the formation of coalitions. The principle of the coalition consists in temporarily putting together several agents for reaching a common goal. Adaptive approach [10] [11] [12] [13] is composed of two stages, the formation of agent coalitions according to their ability to be involved in the desired effect. Then the negotiation between the coalitions to choose the one that provides the closest response to the desired effect.

In the process of the formation of coalitions, an agent may be initiator or candidate. Any agent whose ability can partially fulfill the desired effect can be a coalition initiator. The initiator exchanges messages with other agents, potential members of the coalition, called candidate agents. The Protocol is based on exchanges of messages between the initiator agent and candidate agents. As soon as the overall ability of the coalition is close to the desired effect, the initiator agent is waiting for the negotiation phase.

3.2 Negotiation

At the end of the formations of coalitions, each initiator agent that is the referent of the coalition is negotiating with other initiator agents in order to choose the winning coalition. The coalition whose ability is the closest to the desired effect is the winner. The principle is simple. Each initiator agent sends a message that contains the ability obtained by its coalition. On receipt of this message, each initiator agent compares the ability of the coalition it received to its own one. If its *ability* is lower than that received, its coalition will be no more considered, otherwise, it is a winning coalition up to the reception of a new message.

3.3 Combines Training Criteria

Apart from the desired effect, the formation of coalitions uses other criteria for reducing the response time such as the topological neighbourhood or the obsolescence of a measure when the desired effect depends on sensor data. When no coalition is able to fulfil the desired effect, a new search for a successful coalition is restarted by relaxing the constraints on certain criteria. In order to illustrate the adaptation principle, we present the example of the robot localization in the framework of the scenario of the Quovadis project, described in the introduction. The fall of a patient sets off an alarm which activates the robot. The role of the robot is to look for the person. First, before moving, the robot needs to know its own exact position in the residence. Environment sensors provide more or less accurate location information. The goal of the localization task is to find a combination of the sensor measures. In our approach, the robot sends a localization request in which precision and time constraints are specified. The MAS sets off the adaptation mechanism to fulfill the requested effect. The adaptation process takes into account some criteria, in this case the agent ability to answer localization effect, the agent neighbourhood, the measure availability. We have added higher level constraints which are related to the person service, for example the level of intrusion and the degree of emergency. If at the end of the phase of coalition formation, no coalition is winning, the level of intrusion of the system is increased to the detriment of the patient tranquillity. In fact, increasing the level of intrusion allows the activation of a pan-tilt camera for acquiring new measures and restarting the process of localization by searching a winning coalition.

4 Conclusion

Adaptation is needed to address the dynamic character of ambient environments. The response that we propose is based both on the choice of a distributed architecture but also of coalition and negotiation mechanisms. Robot-environment cooperation architecture is composed of the MAS processing module, the ontological knowledge base and the gateway with the ambient environment. The environment includes communicating objects and one or more robots. To address the problem of adaptation according to the ambient context and quality of service like the level of user discomfort, we relied on the formation of coalitions whose purpose is to respond to a requested effect according to criteria including the level of discomfort.

The evaluation of the architecture and the adaptation mechanisms in a real situation is in progress. The desired effect is the location of the robot. This function is essential to the mobility of the robot. Mobility is the main advantage that robots can add to services to the person.

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Medical Expert Support Tool (MEST): A Person-Centric Approach for Healthcare Management

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Abstract. The Medical Expert Support Tool (MEST) is aimed at helping the clinician in recognizing risk factors in the patient status by offering a multiparametric overview, and by highlighting the individual situation using meaningful colors (green, yellow and red) in order to compare the person physiological parameters with the computed profile. The medical professionals configure the conditions (relevant parameters, thresholds, rules and alerts) setting the values to the decision support modules and receiving the risk assessment results. Finally, interventions should be done depending on the evaluation of the patient. The tool has been designed along with the clinician involved in the project and it will be fully tested and evaluated during the observational study (100 patients) starting on June 2012.

Keywords: Medical Expert Support Tool, risk assessment, healthcare, person-centric, user-centered design.

1 Introduction

Chronic diseases, such as heart disease, stroke, cancer, chronic respiratory diseases and diabetes, are by far the leading cause of mortality in the world, representing 63% of all deaths [1]. The quality of life of such patients is severely affected by complications and continuous visits to hospitals to monitor physiological parameters increasing thus healthcare and social costs.

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The Medical Expert Support Tools (MEST) is a set of UI-based tools built on top of Computer Based Clinical Decision Support System (CDSS) of the system. They have the purpose to help the medical professionals to detect risk from chronic disease monitoring and subsequently to manage the risk in terms of assessment and intervention to mitigate the dangerous situation related to the detected risk factor.

Clinical decision support systems, CDSS [2], must be integrated with a health care organization's clinical workflow, which is often already complex. MEST does not add more complexity on top of preexistent clinical systems but is fully integrated with them, whether they are based on EHR [3] or not.

Similar existing tools as QRISK2 [4] cardiovascular risk score (designed to identify people at high risk of developing CVD) and ARRIBA [5] risk calculator (designed to calculate the risk of experiencing a heart attack or a stroke) are not focused in the continuum of care of the patients.

MEST provides the medical professionals with a multiparametric view and an overall status of the patient indicating the risk factors with meaningful colors (green, yellow and red). The assessment of the person's risk based on the analysis of the information already stored in the system offers the doctor a clear insight of the current situation of the individual. The detection of critical situations will activate the feedbacks to the patient and to the clinicians.

The solution provided to the medical professionals has followed a person-centric approach allowing the patients acceptance through the non-invasive and personalized risk profile. To reach the goals, a clinical expert workflow, which describes the steps of the system, has been designed by interviewing the medical professionals involved. The general schema of the workflow developed is shown in Fig 1.

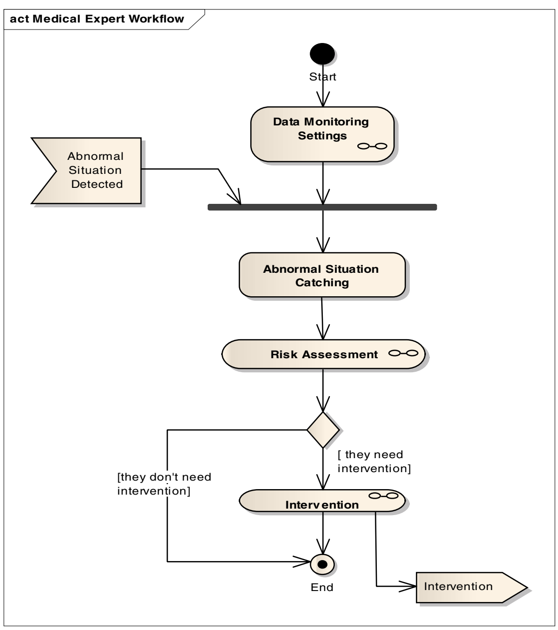

Fig. 1. MEST workflow

The medical professionals access the MEST UI via https (internet/intranet) and it consists of three parts:

Data Monitoring Settings. It sets the inputs to the corresponding decision support system modules in order to configure the system

- **Prioritized Parameters.** Stand-alone application which finds relevant parameters to be measured.
- **Personalized Monitoring Settings.** Parameters, thresholds, rules and feedbacks configuration by the clinician.

Risk Assessment. This module receives the information from the Decision Support modules in order to give the proper risk factor to the doctors.

Interventions. It permits the doctor to manually (or with automatically generated suggestions) interact with the user once all the information coming from the Decision Support System is analyzed.

2 Person-Centric Designed Approach

The User-centred Design methodology is a user- and task-oriented requirement engineering methodology that integrates system level requirements and usability requirements in a holistic elicitation and specification approach.

This methodology follows a User-centred Design (UCD) method and all the stakeholders are to be involved in the capture of the user requirements and integrate Requirement Engineering and Usability Engineering to achieve a better user-centred approach. It includes the definition of user-centred techniques to elicit non-functional requirements in the AAL context and will ensure that the methodology has considered all potential users and stakeholders interests, needs and wants and has adequately involved them in all phases of development (user needs, specifications, design and development, interactive testing, dissemination, exploitation and training).

The UCD guidelines herein are to be used for User and Stakeholders Groups profile identification, User Requirements extractions, applications development, realization of pilot plans and verification activities in the User-centred Design methodology.

ISO 9241-210:2010 [6] has been followed to design the methodology process model to help designers to fulfil the goal of a product engineered for its intended users. This standard provides requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems.

Several phases have been proposed for the development and validation process of the solution, (i) Analysis Phase, (ii) Design Phase, (iii) Implementation Phase and (iv) Deployment Phase.

The stakeholder collaboration was crucial. The doctors involved in the project helped in the requirements elicitation and also during the design and the implementation phase. The first unit tests have been carried out by the cardiologist in order to improve the tool in an iterative process.

3 Medical Expert Support Tool (MEST)

The MEST workflow starts with the pre-configuration of the systems, which means the selection of the parameters for each patient. The Prioritized Parameter (PP) component gives the doctor new findings in order to take into account more information. The second step consists in the selection of the parameters and thresholds needed for the decision support module depending on the patient's health.

The risk assessment component is divided into three sub-components using three different approaches. The expert system sub-component incorporates existing medical knowledge. The machine learning sub-component learns the relation between the parameters characterizing the patient's health and his/her risk using an Artificial Neural Network. The anomaly detection sub-component detects anomalies in the values and relations between the values of the parameters characterizing the patient's health, using the Local Outlier Factor algorithm.

Once all the above mentioned parameters are set, the risk assessment starts and the status of the patient is shown evaluating the risk factors. Finally the required intervention is made depending on the risk detected.

3.1 Prioritized Parameters

This component focuses on the identification of monitoring parameters that are characteristic for CHF patients and have great impact on their health status. In order to follow such a personalized approach data mining techniques have been implemented by employing pattern mining methods. The module is capable of extracting previously unknown patterns through an automatic analysis on large amount of gathered medical data and discovering associations and possible hidden relations between extracted parameters from various clinical data sources.

The proposed mining pattern follows the definition of an association rule, X=>Y, where X, $Y \in I$ are called antecedent (Left Hand Side, LHS) and consequent (Right Hand Side, RHS), with being a set of n binary attributes called itemset. Each item of the rule can be a parameter name or a combination of parameters with correspondent ranges. For example, rule ST [-2,-0.5] => STATUS [normal] can be read as "ST parameter that its value ranges from -2 to -0.5 implies a normal STATUS".

The input to the module is a labeled dataset, converted in readable format by discretization functions mainly, which may come from a classification mechanism or from medical experts. Since the generated rules are semantically weak, there is no guarantee that these rules implied any deeper relationships. The key idea is to use only the "interesting" association rules. This choice is based on the use of objective measures which can filter and sort automatically large quantity of generated rules.

The medical expert through the use of a GUI is able to further process results taking advantage of the options listed below:

- Prune in advance the number of the rules to be generated by configuring (manually or automatically) minimum support and minimum confidence values accordingly.
- Discard rules that show independency between RHS and LHS of a rule (manually or automatically). Compare all results using the overall view in the GUI.

- Sort the rules per different metric value focusing each time in different property regarding the relationship between the attributes of the rule.
- Compare the strength of rules given the same antecedent and more specific when the antecedent is the "ABNORMAL" status of the patient. This kind of enhancement aims to determine the strongest direction of the rule.

The medical expert can observe and sort the rules depending on a metric that evaluates its strength (including confidence, lift, leverage and conviction) and can evaluate the patterns in order to reconsider past or future decisions that need to be taken for the patient's monitoring and treatment. As the amount of medical data increases the performance of the algorithm is enhanced. However it is important to underline that this application has an advisory role for the medical expert.

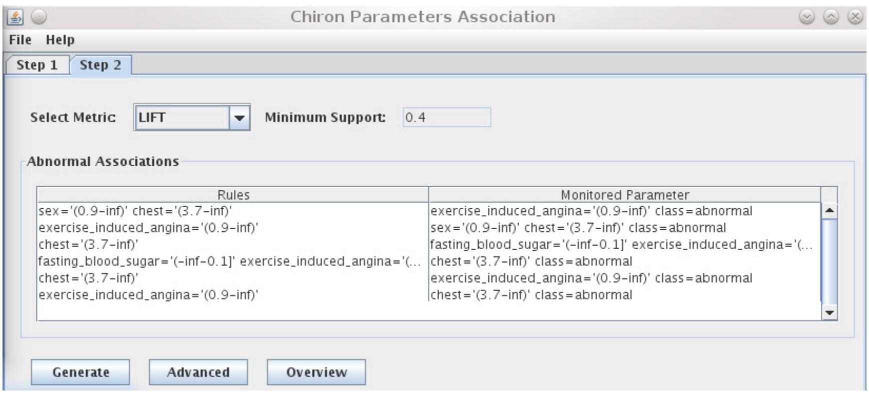

Fig. 2. Screenshot of the priority parameters module

3.2 Monitoring Settings

The Monitoring Settings is the system pre-configuration in order to prepare the decision support modules and set the corresponding boundary values (high and low). After receiving the relevant parameters from the Prioritized Parameters component the medical professionals set the parameters, rules, thresholds and alerts in order to configure the Risk Assessment module. All the elements get the data from a common repository. Once the clinician has set the parameters, he/she has to define a set of rules in order to send personalized feedback to the patients. All the configuration thresholds can be computed dynamically (intelligent system) based on past experience of certain diseases, but it also includes manual interaction, it means, the doctor could set the values using the GUI.

The Monitoring Settings module describes the parameters which, automatically or manually guide the patient profile and the rules-set configuration to trigger the corresponding feedbacks to the clinician and patients. The Medical Expert Workflow sets up the inputs (values) to the other components and could also receive the corresponding outputs (suggestions).

Once the modules huyave been configured the risk assessment process is started and the tool guides the doctor in knowing the factors which influence the patient status.

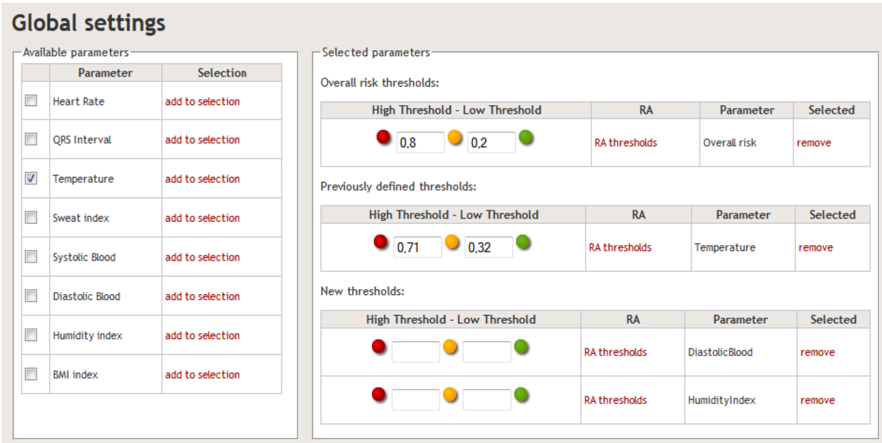

Fig. 3. Monitoring Settings GUI

3.3 Risk Assessment

The risk assessment procedure is the central part of the workflow where the clinician is expected to review the clinical status of his/her patients and subsequently schedule an intervention if needed.

This procedure is preceded by the "Abnormal Situation Catching" step of the workflow. This is where the clinician is presented with the list of his/her patients (Fig 4). Every patient is associated with a brief evaluation of his/her overall risk factor by means of a green/yellow/red mark.

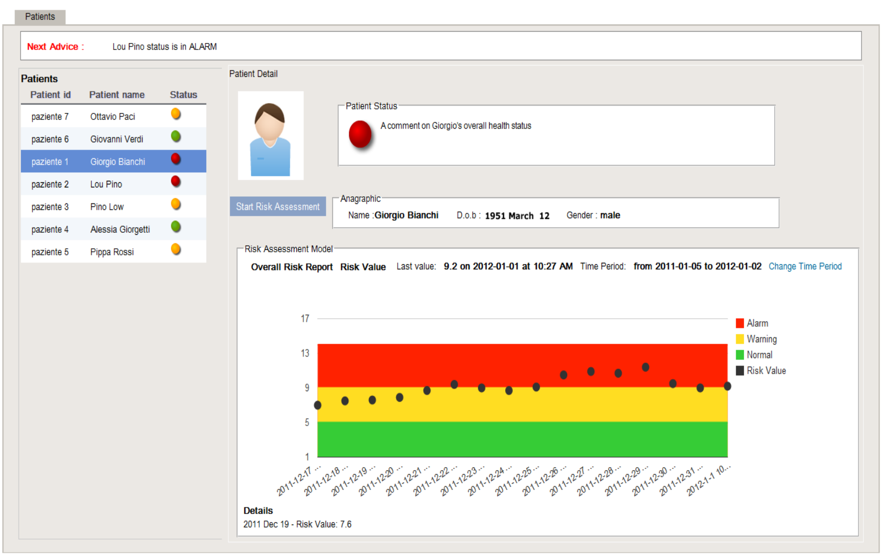

Fig. 4. Abnormal Situation Catching

The evaluation of this factor is performed automatically by the system basing on patient's profile (e.g. configured thresholds and parameters) and clinical data. Upon selection by the clinician, the system shows a more detailed view of the patient; this view includes patient's anagraphic data, and a (configurable) number of recent-past evaluations of the patient's risk factor. This last set of data is presented in a graphical way that highlights the overall trend for the selected patient, in order to ease the clinician's task to decide whether the patient's health status needs to be assessed.

If this is the case, the system will start a new Risk Assessment procedure, whose goal is to let the clinician decide whether the selected patient needs an intervention of some kind (e.g. modify the medical treatment) or the risk factor of the patient can be considered acceptable. During the procedure, the clinician can access a very broad spectrum of information regarding the patient, ranging from the patient's history of all the causes that led to the evaluation of a risk factor at a certain point in time, to the complete history of his monitored clinical parameters, along with a large database of clinical literature related with the disease of the patient and his/her monitored clinical parameters.

3.4 Interventions

The risk management could require one or more interventions from the medical professional depending on the assessment of the patient’s risk. The sort of intervention(s) is included by the clinician in the user interface, and it could be automatic or manual. The list of actions done reacting to the situation of the person is shown to the doctor. After the intervention is carried out, the decision process is considered completed.

The component shows the information of the causes of the intervention. The users can insert the corresponding notes about the actions done or to be carried out. Once the intervention is made, clinicians can complete the workflow. The automatic actions (SMS, email, etc) are also visible to the doctor in order to be aware of the communications maintained with the patients.

4 Conclusion

The healthcare management nowadays focuses on the diagnosis of the patients suffering from chronic diseases, which means, the person has to wait until an episode in order to be treated. The Medical Expert System Tool intends to stress in the prevention, monitoring the vital signs and evaluating the results comparing them to some computed profile coming from Decision Support modules.

The tool has been developed using an open and scalable design, receiving the results in a standard way. This way, different components could be applied depending on the patient’s chronic disease to be monitored, because the parameters, their thresholds, rules and feedbacks are configured by the clinicians at the beginning of the workflow which guides the medical professional in the individual’s follow-up.

The system allows the doctors to estimate the patients’ status, positioning them in the tri-color flag (green, yellow and red). With a quick look the clinician can understand the values of the parameters studied and the possible risk factors.

More and more people trust the new technologies and tools have been proved to have the ability of "foreseeing the future" in certain cases. "Not seeing, still we know / Not knowing, guess / Not guessing, smile and hide".

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The Integration of e-health into the Clinical Workflow – Electronic Health Record and Standardization Efforts

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Abstract. The continuous increase in the number of different devices within medical information systems produces a large amount of heterogenic clinical information which must be integrated and correctly stored in order to improve patient's health and decrease healthcare costs. The use of the universally recognized standards of information and knowledge transmission and storage can be an excellent instrument to develop innovative eHealth solution. A EN13606 compliant telemonitoring solution is described in this paper; it is based on a collection and a semantic organization of sensor data, a standardized information transmission and storage within an internal repository during the monitoring period. This solution represents an example of care continuum concretization completely integrated with the European Health System directives.

Keywords: semantic interoperability, eHealth, standardization, Smart Space.

1 Introduction

Recent studies [1] have shown the impact of eHealth to healthcare and healthcare costs. The NHS (National Health Service) performed the world largest study on eHealth which involved 6.000 patients. This study stated that, by using eHealth: the number of acute admissions decreased by 20%, the number of acute hospitalization cases was reduced by 14%, the number of patient-days in hospitals also went down by 14% and costs decreased by eight percent. Above all, the mortality in this study was 45% lower than in usual care.

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The European Commission provides an insight into innovation barriers for eHealth [2]. In barrier 12 "*Lack of standards*", it was judged that there is a huge lack of understanding of the standards in order to better semantic and functional interoperability in healthcare systems. The most common misunderstanding is that HL7 is a standard on its own, but it is not; it is a set of standards. HL7 is in its base a message broker, defined for instance by HL7 v2 (Unifact and Edifact) and HL7 v3 (XML scheme for messages). And in ICT it is common known that one cannot create semantic interoperability based on a message broker, therefore a reference Architecture is needed. This Reference Architecture is defined in the ISO/EN13606 and applied in either HL7 CDA or openEHR Archetypes. This paper describes eHealth as the continuity of care that can be supported by several tools and that can follow each patient in any aspect of his/her normal life. In cases of severe chronic diseases, as in cardiovascular conditions, the permanent monitoring of the status of the patient can be a life saving tool [3].

At present, the continuous increase in the number of different devices, based on heterogenic technologies, within medical information systems, produces a large amount of clinical information about patients in all types of proprietary formats. Moreover, state-of-the art technologies provide instruments to design and develop innovative solutions which are able to enlarge the actual boundaries of healthcare beyond the hospital environment. This means that data sources can gather quality information independently from the site of measurements [4]. Consequently, in many developed countries health authorities are planning the creation of a life long health record diary which aims to contain all relevant clinical information which is organized in a structured environment; referred to as the Electronic Health Record (EHR) [5]. The concept of the EHR is defined by Iakovidis as "digitally stored health care information about an individual's lifetime with the purpose of supporting continuity of care, education and research, and ensuring confidentiality at all times" [6]. The EHR can collect varying types of information (observations, laboratory tests, diagnostic imaging, etc.) which are typically stored in different proprietary formats. Typical formats are for example, relational database tables, structured document-based storage and unstructured document storage (digitized hardcopies maintained in a common document management system) [7]. Among some applications of the EHR, the implementation at the Muenster University Hospital called *akteonline.de* is worthwhile describing briefly. The aims of this EHR are:

- to give citizens the possibility to be in charge of their own health record electronically;
- to provide access to this record through the internet independent of place and time;
- to present personalized health information online;
- to serve as a medium for sharing selected areas of health information with caregivers (which can be used as a communication between medical professionals, but under control of the concerned patient) [8].

This EHR solution is well structured, in order to provide citizens with a tool to insert and store parts of their medical data manually; instead it encounters difficulties in integration with solutions which transfer information automatically and independently from the site of the patient, as in common telemonitoring. This aspect is highly significant as one of the prominent research directions in the medical field is based on developing frameworks to improve health knowledge and processes for prevention and treatment of acute episodes. A smart and innovative solution, which is able to provide both personalized telemonitoring and the management of patient's health status, must ensure: the interoperability between heterogeneous devices and services, a reliable and secure patient data management and a seamless integration with the clinical standardized workflow.

This paper presents a specific implementation of this concept for people suffering from Congestive Heart Failure (CHF) class III [9].

2 Material and Methods

The material utilized in this work is related to clinical data obtained from patients affected by CHF; this data must follow a particular workflow. According to the specific medical guidelines, these patients had already been hospitalized and the large amount of data, collected during this period, is accessible through the institutional EHR. Due to their critical health condition, after the hospitalization, these patients must be continuously telemonitored and the information collected is extremely important: as it is possible that these patients could have to be readmitted and, in this case, it is useful that the information is again available to the institutional EHR.

In order to efficiently implement this workflow, the following section should be included into the proposed system:

1. A Virtual Data Repository (VDR) internal to the system which maintains the same features of an institutional EHR for all of the telemonitoring period;
2. Standardized interfaces to allow a bidirectional relationship between the institutional EHR and the internal VDR;
3. A collector to harmonize extremely fragmented signals coming from sensors placed on the field (Smart Space).

The system architecture followed the indications provided in the CEN/ISO 13606 (also called EHR.com). Specifically, during the implementation of interfaces two different, but equivalent approaches were used: the openEHR and the HL7 version 3 Clinical Document Architecture Release 2 (CDA R2). In both cases it was decided to use an information transmission based on the HL7 v3 message. Finally, Smart Spaces were used for the collection and semantic organization of information derived from the sensor network.

2.1 Different Reference Models

EN13606, openEHR and HL7-CDA are based on different Reference Models. These Reference Models are in fact more or less generic class-structures and data type-definitions which are able to describe the health related objects (for example, medical condition).

One health related object can thus be described inside different Reference Models. And there are varying ways to describe a health related object inside the chosen Reference Model.

The Main EU Standard for an EHR: The Approved CEN/ISO 13606 (EHR.com). CEN13606 leaves considerable space to adapt the implementation of the standard to local circumstances and organization maturity. The archetype model combines a deterministic view with the possibility to make a trade off towards local habits and particularities. The main architectural features are; to act as discrete systems or as middleware components; to access, transfer, add or modify health record entries; to operate via electronic messages or distributed objects; to preserve the original clinical meaning intended by the author; to reflect the confidentiality of that data as intended by the author and patient. In order to fulfill these requirements, the goal was to specify the information architecture required for communications interoperability between systems and services that might request or provide EHR data. This standard is neither intended to specify the internal architecture or database design of such systems, no to prescribe the kinds of clinical applications that might request or contribute EHR data in particular settings, domains or specialist fields. For this reason, the information model might be used to define a message, an XML document or schema, or an object interface as described in CEN/TC 251/N04-012 published on Health Informatics in 2004. The ISO/CEN13606 parts:

- Part 1: Reference Model
- Part 2: Archetype interchange specification
- Part 3: Reference Archetypes and term lists
- Part 4: Security requirements and distribution rules
- Part 5: Interface Specifications

In this project two different approaches were used (reference architectures) to meet the requirements of the EN13606; the openEHR approach is submitted to the VDR, the HL7 CDA approach is submitted to Smart Space. The external messaging for both approaches is HL7 v3 (SOAP).

Virtual Data Repository (VDR).
ZorgGemak's VDR Kernel is built on the scientific approach of the openEHR specifications. The Interface of the Kernel is SOAP, whereas middleware on top of the SOAP layer separates GUI from the Kernel by REST services. This transparent approach guaranties safety and ability to add services (like local regulations) without changing the architecture.

The OpenEHR Reference Architecture describes a two-level modeling methodology and two sets of specifications; an information part and a knowledge part. The first one defines a stable reference model that describes the EHR as a container that holds compositions (documents) which in turn may have entries (observations, evaluations, instructions, etc.). Although the selection of entries is based on a certain model of decision making in healthcare, the model itself does not attempt to represent clinical knowledge. It comes from a variety of sources such as terminologies, ontologies, classifications and measurement systems; the application of computable knowledge representation to the information model is how data acquires its context-specific meaning. The full computable data models of clinical concepts are called archetypes: for example, blood pressure is an archetype, as is a synoptic report or a pathology lab result.

An important feature of the openEHR environment is that the modeling of the data is not enforced by the openEHR environment but by archetypes. The basis of all data-modeling is in the reference-model, which allows very flexible modeling. Although it was enhanced for use with medical-orientated data.

The archetype is meant to represent all the clinical knowledge regarding a certain concept. However, in order to make a practical use of archetype libraries we combine them. For example a medical specialist may specify the need for the systolic and diastolic blood pressure, and the arterial, or the pulse, but might not be interested in discussing whether the patient was for example, sitting or standing.

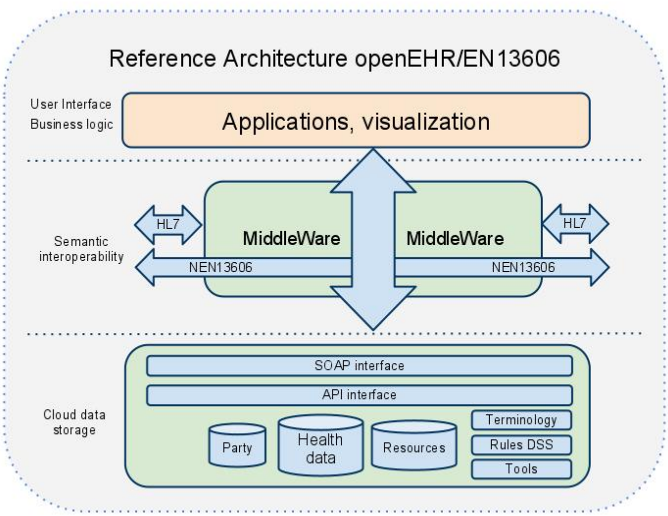

Fig. 1. Reference Architecture openEHR/EN 13606

In different circumstances, e.g. in sports medicine a baseline reading may be required and then repeated every 5, 10 mins. Archetypes allow for different constraints in different formats (GUI), so long as the same basic clinical models are used. Once the GUI is selected the semantics can be further enhanced by querying available terminologies (SNOMED, ICD) and producing bindings to the terminology subsets that should be used with particular archetypes. If the understanding of medicine is enriched, a new version of the archetypes can be produced, or in order to satisfy specific requirements.

HL7 v3 CDA R2.

The Clinical Document Architecture Release 2 is a document markup standard developed by HL7, encoded in markup languages such as XML or RDF, that specifies the structure and semantics of a clinical document for the purpose of exchange. HL7 CDA R2 provides an object model in order to represent a technical diagram of the CDA specification and structure. The basic structure of CDA Release 2 is formed by two parts fully HL7 v3 RIM (Reference Information Model) derived: a *header* and a *body*. The *header's* purpose is to set the context for the document as a whole, to enable clinical document exchange across and within institutions, to facilitate clinical document management and to facilitate the compilation of an individual patient's clinical documents into a lifetime electronic patient record. The *body*, contains the clinical report and it can be either an unstructured blob or can be comprised of structured markup. In the second case, the *body* is divided up into recursively nestable document *sections*. Each *section* contains a single ''*narrative block*'', any number of CDA *entries* and external references (such as other images, procedures, or clinical documents). The ''*narrative block*'' represents the content to be rendered, which is expressed in human language. Every *section* can contain a *clinical statement* which could be one of the following: an *observation*, a *substance administration,* a *supply*, or a *procedure*. Each *clinical statement* in turn can relate to another one through a semantic relationship (e.g., cause, component, reason) [10].

2.2 Smart Space

The Smart Space (SS) platform is a solution which is able to share the understanding of information significance in order to provide a semantic interoperability of information collected by heterogeneous devices and sensors. SS manages and stores information about entities existing in the physical environment, that is, the users, the objects surrounding them, the devices used, or about the environment itself. In its architecture Smart Space has two main actors: the semantic information broker (SIB) and the knowledge processor (KP). The SIB is a digital entity which stores and keeps up-to-date significant real-world information. The information model is a directed labeled graph corresponding to a set of Resource Description Framework (RDF a basic semantic web standard) triples. In order to specify information semantics, ontologies defined in OWL (Web Ontology Language) are used. The KPs are software components able to interact with the SIB, produce and/or consume data. The legacy adapters are KPs that enable legacy SS-unaware devices to exchange information with the SIB. In order to allow KP to exchange data an application layer protocol based on XML (eXtensible Markup Language), Smart Space Access Protocol (SSAP), is defined. It provides a simple set of messages (join, insert, remove, update, query, subscribe, and leave) that can be used in multiple connectivity mechanisms. In the biomedical context, this platform can be used as the core of this telemonitoring alarm system: every patient has its personal Smart Space that manages information collected from heterogeneous devices together with the user profile; due to its publish/subscribe mechanism, the solution is responsible also for an event or a notification [11].

3 Results

The EN13606 compliant telemonitoring solution which is proposed in this article is composed of:

- A Virtual Data Repository, based on openEHR specifications, to collect information and knowledge about the patient which is then presented via a semantic interoperable Web Service;
- A Body Sensor Network (Smart Space), based on HL7 CDA specifications, to collect and semantically organized information coming from monitoring sensors;
- A Web Service, based on the message broker HL7 v3 (SOAP), which provides a standardized interface to allows bidirectional communication between either Smart Space-VDR and EHR-VDR. Both HL7 CDA and openEHR Archetypes.

3.1 Clinical Information Workflow

In order to allow a correct interpretation of the clinical information workflow, three different storyboards are presented below (Figure 2).

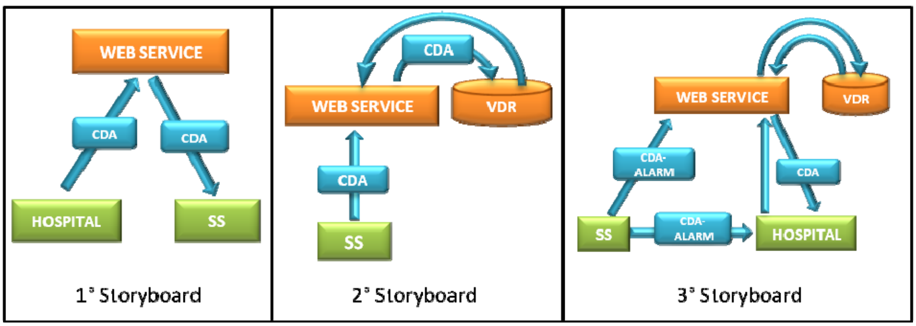

Fig. 2. The clinical information workflow: the three storyboards

In the first storyboard, the patient is discharged from the Hospital and from now on she/he will be monitored at home by the Smart Space platform; the care structure Information System uses a specific Web Service function to send the complete Clinical Document Architecture to the SS system. This document contains the information necessary to enable a new registration on the patient's specific SS: the threshold values for the clinical observations for this patient, required to set the alarm criteria on SS. In the same time a new Virtual Data Repository is initialized. The second storyboard describes a typical information update within Virtual Patient Repository. The Smart Space platform collects and semantically organized all the information, coming from the patient's Body Sensor Network, within the Semantic Information Broker. Several times a day, a specific Knowledge Processor interacts with SIB and produces a CDA which contains, within the key elements Observations, the semantically organized information which is collected in that specific time interval. Afterwards, the KP sends this CDA to the Web Service which temporarily stores these Observations until the VDR calls the specific service to be updated with the new information. In this way, the Web Service prepares a CDA which contains all the Observations temporarily stored within its local database and sends it to VDR.

In the third storyboard the critical situation is represented in which one or more vital sign measured are out of range, so the KP prepares and send a CDA broadcast alarm message both to Web Service and to the Hospital Information System. Due to this information, the Hospital Information System is informed about the critical health status so it can organize the appropriate assistance and prepare the patient readmission. In fact, it can call the specific Web Service function to obtain a CDA which contains all the relevant information collected within the VDR in all of the telemonitoring period. Therefore it is able to update the EHR of the patient who is to be readmitted.

4 Conclusions

In this paper a telemonitoring solution which ensures the integration of e-heath into the clinical workflow is presented. This is possible thanks to the use of the universally recognized standards – EN13606 (EHR.com) with two different specifications; openEHR and HL7 v3 CDA R2 – for the information and knowledge transmission and storage. Both solutions communicate in the XML message defined by HL7 v3.

Acknowledgment. This work was developed within CHIRON project of the European Joint Undertaking on Embedded Systems ARTEMIS and is co-funded by the EU and by National Authorities (GA n. 100228).

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Innovative Solutions in Health Monitoring at Home: The Real-Time Assessment of Serum Potassium Concentration from ECG

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Abstract. Maintenance of normal potassium homeostasis is increasingly an important limiting factor in the therapy of several diseases including patients with heart failure. Nowadays, quantification of potassium concentration in the blood ($[K^+]$) is invasive and laboratory-based. The aims of the study were to develop a method quantifying $[K^+]$ from the electrocardiogram (ECG) and validate it on 13 hemodialysis (HD) and 7 congenital long-QT type 2 (LQT2) patients. Reference values were obtained from blood samples. An ECG-based potassium estimator (K_{ECG}) was defined and compared to the reference values. Data from 33/39 HD sessions gave consistent results. In 6 sessions, the presence of a systematic error inhibited reliable estimates. Patient specific calibration allowed good agreement in all HD patients (error: -0.04±0.61mM). As expected, $[K^+]$ was significantly underestimated in LQT2 patients (error: 1.24±0.75mM, p<0.01). Preliminary results show K_{ECG} estimates can be an effective tool for hyper/hypokalemic risk patient monitoring at home.

Keywords: electrocardiography, potassium, home health monitoring, kidney, long-QT syndrome.

1 Introduction

Maintenance of normal potassium homeostasis is an important limiting factor in the therapy of cardiovascular diseases. Many pharmacological agents that reduce morbidity and mortality in patients with complicated myocardial infarction and chronic heart failure (HF), including β-blockers, angiotensin-converting enzyme inhibitors, angiotensin-receptor blockers, and aldosterone receptor antagonists, are also known to raise serum potassium and augment the risk of life-threatening hyperkalemia. Conversely, loop diuretics, a mainstay of heart failure treatment, tend to enhance the risk of hypokalemia and ventricular arrhythmias, which may in part account for their consistent dose-related association with increased mortality in observational studies. Because combination drug therapy may simultaneously improve clinical outcomes and enhance the risk of potassium-related adverse events, an appropriate balance of benefit and risk depends heavily on careful patient selection

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and adequate surveillance of serum potassium [1]. Therefore a noninvasive monitoring of serum potassium would be of great importance and useful especially in patients already undergoing specific monitoring, including home monitoring.

Nowadays, the only available measurement for $[K^+]$ is laboratory-based through blood samples.

Electrocardiographic effects of potassium are well known since many years [2,3]: the earliest electrocardiographic manifestation of hyperkalemia is the appearance of narrow-based, peaked T waves (Fig. 1); in addition QT segment duration (QTc) [4] and repolarization complexity [5] have also been associated with potassium levels in dialysis patients.

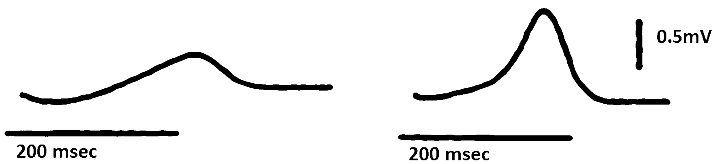

Fig. 1. Alterations in T-wave due to different potassium level (from [6]): a typical T-wave pattern in hypokalemia ($[K^+]$ = 2 mmol/L) on the left panel and a typical T-wave pattern in hyperkalemia ($[K^+]$ = 6 mmol/L) on the right panel

Several studies in the literature are focused on blood potassium concentration quantification through electrocardiogram (ECG) analysis [7-10]. Herzog et al. [7] showed that qualitative evaluation of electrocardiogram changes to diagnose potassium level resulted in poor sensitivity and specificity. Wrenn and colleagues [8] designed their study to determine whether physicians blinded to the serum potassium level can predict potassium concentration of more than 5.0 mmol/L from the ECG; the results showed the sensitivity and specificity of the readers were at most .43 and .86, respectively. In spite of preliminary positive observations [9], Aslam et al. showed that the height of T waves does not correlate with $[K^+]$, even if normalized to QRS, especially in dialysis patients [10]. Frohnert et al. were the first to attempt a quantitative assessment of serum potassium level from ECG derived parameters (T-wave amplitude and maximum time) in patients with chronic heart failure [11]. However, this $[K^+]$ estimator was not applied on data from additional patients to test the robustness and validity of the method and did not reach clinical application. Overall, up to now, attempts for a qualitative evaluation of electrocardiogram changes to diagnose potassium level resulted in poor sensitivity and specificity and quantitative measurement of the height of T-waves did not correlate with $[K^+]$. The reason of this is probably the simple T-wave amplitude is a poor marker of serum potassium influence on cardiac repolarization since it is influenced by many other factors.

In this study we developed a new automatic method to quantify $[K^+]$ from T-wave analysis in real-time from ECG and validated it on data from consecutive dialysis patients, since they have wide fluctuations in serum potassium pre- and post-dialysis. In addition, to give a mechanistical interpretation of the link between $[K^+]$ and ECG the estimator was tested on congenital long QT type 2 (LQT2) patients, where such link is likely to be disrupted.

2 Method

We hypothesized that the morphological changes in the T-wave due to changes in potassium could be captured by a combination of simple measurements reflecting at what extent the T-wave is "narrow and peaked". In other words, we looked for a way to describe an amplitude-invariant measurement of the sharpness of T-wave and defined a direct relationship between the ratio of the T-wave slope to amplitude ($T_{S/A}$) and serum potassium (Fig. 2).

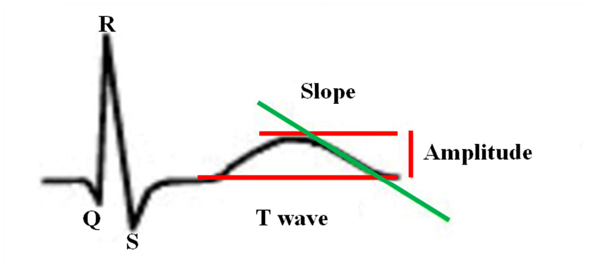

Fig. 2. A typical QRS-T wave complex from a representative electrocardiogram together with the schematic explanation of the negative slope and the amplitude of the T wave used for $[K^+]$ estimation

Based on the relationship we defined an estimator from which the $[K^+]$ values were derived. We retrospectively analyzed 12-lead Holter ECG recordings (H12+, Mortara Instrument Inc.). The most significant two eigenleads were used to calculate the downslope and the amplitude of the T-wave for each beat. Once the value of $T_{S/A}$ was known the concentration of serum potassium was derived by considering a 2-minute window median value of the $T_{S/A}$ at 15 minute intervals and an ECG-based potassium estimator (K_{ECG}) was defined as a linear function of $T_{S/A}$.

A qualitative example of ECGs underlying single estimates and the correspondence between $[K^+]$ and T-wave morphology in a real patient is shown in Fig. 3.

The new method we developed was tested on data from consecutive dialysis patients (HD), since they experience wide fluctuations in in blood composition and hemodynamic parameters including serum potassium pre- and post-dialysis. For this reason hemodialysis therapy is a unique "experimental model" for this testing. In addition, in this population, the reference values for $[K^+]$ measured through standard laboratory analysis are straightaway available through blood samples taken from the extracorporeal circuit.

To validate the developed method we retrospectively examined 12-lead Holter ECG recordings (H12+, Mortara Instrument Inc., 1 KHz) acquired during the dialysis sessions in HD patients. We enrolled 13 patients (age: 76±12 years; 11 men) (3 sessions per patient for 3 weeks, the same day of the week, each session is about 4 hour long). Eligible patients should have been at a metabolic steady state in dialysis treatment for at least 6 months with thrice-weekly and double-needle hemodialysis.

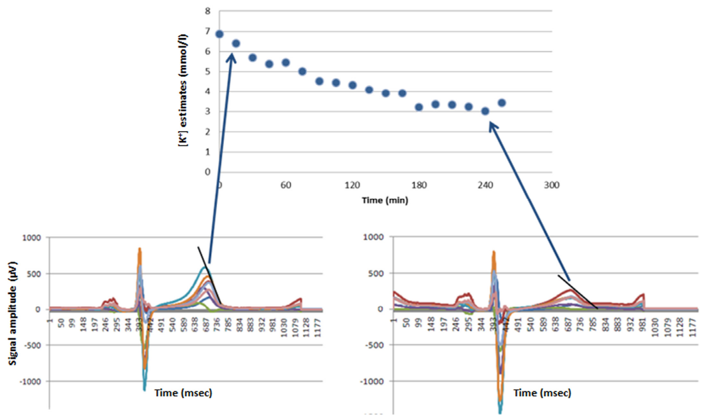

Fig. 3. A qualitative example of ECGs underlying single estimates and the correspondence between $[K^+]$ and T-wave morphology in a real patient during a dialysis session

Exclusion criteria were: diabetes mellitus, pacemaker holders, anemic patient, vascular access recirculation > 10%, history of myocardial ischemia, coronary bypass, atrial fibrillation and ejection fraction < 50%.

ECG data were exported and analyzed by implementing a dynamic link library that interfaces to the post-processing software already available from Mortara Instruments Inc. (SuperECG/Spectrum Mortara Instrument Inc.).

Reference values for $[K^+]$ (K_{LAB}) as well as values of Na^+ and Ca^{2+} serum concentrations were obtained twice at the following times: 0, 30, 60, 120, 180, 240 minutes from the start of dialysis by blood samples (RapidLab 855, Bayer).

For further testing, we also analyzed the estimator on 7 patients with LQT syndrome type 2, a pathology known to affect the link between $[K^+]$ and ventricular repolarization. LQT2 patients carry “loss of function” mutations of the gene encoding for HERG (I_{Kr}) channels. Therefore, the potassium current is reduced in a way, at some extent, similar to that observed in hypokalemic conditions. Based on this observation we hypothesized that ECG based estimator should systematically underestimate blood potassium in this population.

3 Results

A strong correlation (r=0.63, p<0.0001) was found between $T_{S/A}$ and $[K^+]$ in HD patients (Fig. 4).

Based on these results an ECG-based potassium estimator was defined as K_{ECG}=1.34* $T_{S/A}$+1.38 and compared with the reference potassium measurements. The agreement was good (absolute error: 0.49±0.16 mM) for most of the sessions (30/39). An example of the results obtained in one patient is shown in Fig. 5 (left).

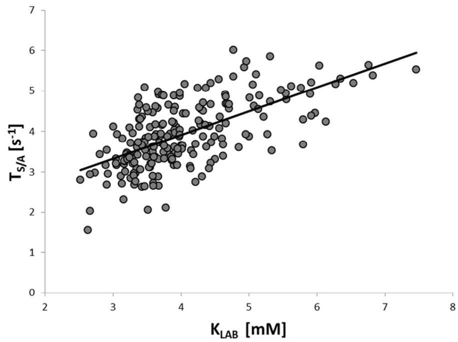

Fig. 4. Linear regression between $T_{S/A}$ and $[K^+]$

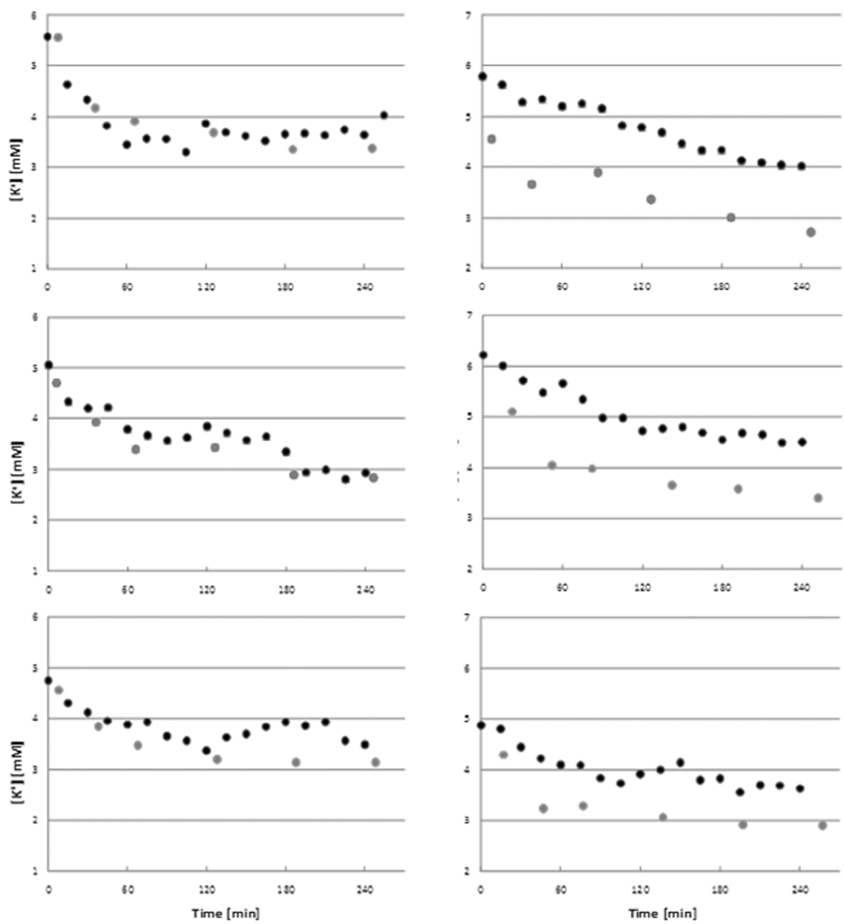

Fig. 5. Example of a good agreement (left panels) and of a systematic error (right panels) between the K_{ECG} (dark points) and K_{LAB} (light points) in two patients in the analyzed sessions

In 9 sessions (absolute error: 1.17±0.36 mM) the presence of a systematic error (bias) all along the session did not allow reliable estimates. An example of a patient in which a systematic error in the [K^+] estimates is shown in Fig. 5 (right).

To optimize these results we looked for session-dependent bias: calcium, magnesium, initial hydration status, pH, HR were considered and excluded.

Therefore, we decided to perform a patient-specific calibration: K_{LAB} (first and last) measurements from first session were used to correct the bias for each patient in successive sessions and the final estimator resulted in: K_{ECG}=1.44* $T_{S/A}$ + patient-bias. Bland- Altman analysis showed a mean error of 0.09±0.59mM and an absolute error of 0.48±0.35mM (Fig. 6).

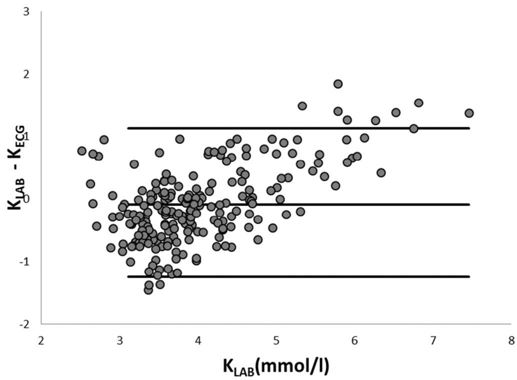

Fig. 6. Bland-Altman plot of the estimated vs the reference values for [K^+]

As expected, in LQT2 patients, our method underestimated [K^+] (K_{LAB}: 4.44±0.31mM; K_{ECG}: 3.2±0.75mM) resulting in an error of 1.24±0.75mM (p<0.01) as shown in the table 1:

Table 1. Results obtained on LQT2 patients

Patient #	Age	K_{LAB}	K_{ECG}
1	22	4.6	2.33
2	34	4.5	2.89
3	7	4.8	3.66
4	53	3.9	2.88
5	42	4.4	4.6
6	32	4.2	2.69
7	35	4.7	3.32

4 Discussion and Conclusion

We proposed a new automatic method for quantification of blood potassium concentration from the ECG.

The treatment of several classes of patients could benefit from a real-time and non-invasive measurement of $[K^+]$. Drug therapies administered to HF patients may improve clinical outcomes and, at the same time, increase the potassium-related adverse events risk. For this reason, an appropriate balance of benefit and risk depends heavily on an adequate surveillance of serum potassium [1]. Since $[K^+]$ measurement is invasive and laboratory-based through blood tests, a continuous serum potassium monitoring is not available and a method allowing it, available also at patient's home, could be extremely useful.

Preliminary results on HD patients are promising and show the K_{ECG} estimates can be an effective tool for hyper- hypo-kalemic risk patient monitoring, which are among the main risk factors for cardiac arrhythmias as well as being indicators for worsening of heart or kidney conditions.

Data acquisition was not particularly challenging: blood samples are straightaway available from the extracorporeal circuit and ECG signal can be easily recorded, without any additional invasive procedure or discomfort for the patient.

The accuracy of these results is clinically relevant since a mean error of 0.09±0.59mM on the estimates is acceptable. In addition, $[K^+]$ fluctuations are more clinically useful than single values and the $[K^+]$ trend, even for sessions in which the bias is present, is correctly assessed.

To achieve these results a patient-specific calibration was necessary since we could not find any reason explaining the bias in 9/39 sessions belonging to 3 patients. Further investigations on this session-dependent bias carried out on the influence of other parameters such as calcium, magnesium, initial hydration status, pH, HR could not explain it. Obviously, this patient-specific calibration is possible on HD patients and the possibility of an initial blood test to calibrate the system should be investigated in additional patient populations.

We tested the hypothesis that reduction in I_{Kr} current with $[K^+]$ decrease (a well-known physiological regulation process of cardiac cell electrophysiology) could be the crucial mechanism leading to the change in T-wave morphology we detected with our estimator. In fact, data from LQT2 patients, in which an I_{Kr} reduction is present due to a different pathological factor, show the same estimator reduction we found in hypokalemia condition, thus confirming the dependence on extracellular potassium in determining the link between $[K^+]$ and T-wave morphology.

In conclusion, to our knowledge, this is the first study to develop, validate, and test in the clinical setting a new technique aimed a real time and accurate quantification of serum potassium concentration from ECG. This analysis holds promise for multiple applications and for several diseases, both in a clinical environment and in the scenario of health monitoring at home.

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Assessment of Custom Fitted Heart Rate Sensing Garments whilst undertaking Everyday Activities

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Abstract. This study assesses the accuracy of heart rate detection using custom fit intelligent garments with integrated textile electrodes. Two single lead electrocardiograms (ECGs) where recorded from 5 subjects using wet Ag/AgCl (WE) and textile electrodes (TE). During recording the subjects were asked to perform several tasks. Offline, the ECGs recorded from the WE were examined and the number of R wave peaks for each subject where counted by a human observer. This count served as the gold standard. A computer program was used to detect R peaks from both the WE and TE. Sensitivity of each system was determined by comparing computer program based heart rates from WE and TE to the gold standard. The system with TE obtained a mean sensitivity of 76.47%. This was significantly lower than with WE (mean: 98.19%). Results indicated that the custom skin layers did not perform accurately whilst performing tasks involving movement of the trunk and limbs.

Keywords: Smart garment, wearable sensors, textile electrodes, heart rate, activities of daily living.

1 Introduction

Over the last 30 years the number of persons aged 60 or over has doubled. These figures are set to double again by 2050 [1]. Within this age demographic, older adults who exercise regularly have been shown to benefit from improvements in both mental and physical health. As a result there is a growing emphasis being placed upon the management of wellness, with acknowledgment being given to the role that the home, exercise, and community have to play in an individual's health and wellbeing [2]. Nevertheless, many older adults do not engage in exercise [3].

The design for ageing well project, funded by the UK's New Dynamics of Ageing Programme, aims to investigate the application of wearable technology and smart

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textiles in a clothing system with a specific emphasis on promoting self-monitoring of wellbeing amongst active older people [4].

This paper presents results from investigations which assess the performance of textile electrodes (TE) integrated within custom fitted 'skin layer' garments designed specifically for the active ageing within the 60-75 age group. Data was acquired from a number of participants using garment integrated sensor technologies during a predefined set of activities within a controlled environment. The ability of a peak detection algorithm to detect R wave peaks from a one lead ECG recorded from the two electrode technologies was subsequently assessed.

2 Background

Integrating sensor technology into clothing has many advantages. Devices and wiring can be placed into pockets, seams or integrated directly into the fabric. Furthermore, clothing allows for sensors to be placed within close physical proximity to a large area of the body [5]. Clothing also provides a comfortable sensing platform which is considered to be socially ubiquitous. Finally, clothing ensures sensors are repeatedly placed in the same location which may lead to improved accuracy of the sensor technology and avoidance of misplacement of sensors [5].

Recently, TE have shown promise for the measurement of the electrocardiogram (ECG). As these electrodes do not require a gel membrane or adhesive they are more suited to long term monitoring applications [6].

There are, however, signal quality issues associated with TE. This is mainly due to the large amount of noise produced by variations in pressure on the electrode caused by movement and poor contact between the electrode and the skin [7]. A common approach to reduce the impact of this noise source is to use a very close fitting garment sometimes referred to as a 'skin layer'. This type of garment is designed to mimic, as closely as possible, the movement of the wearer's body. While this approach is successful in minimizing the more significant sources of noise, it will not eliminate the noise completely [8].

When developing garments with integrated or attached sensors it is therefore important to balance the need to maintain bodily contact to improve sensor accuracy with the comfort of the wearer. Furthermore, the performance of these systems may benefit from customization to the individual [9]. Doing so may ensure individualized placement and improved accuracy of the underlying sensor technology.

Within the design for ageing well project we are using novel three dimensional body scanning technology to extract accurate anthropometric measurements of an active ageing cohort [10]. These measurements are then used to create custom fitted garments which are comfortable to wear and also apply the appropriate pressure required for the sensor technology to function accurately.

As part of this, a skin layer garment, containing integrated TE for the detection of heart rate has been developed. This takes the form of a close fitting vest for males and a bra style garment for females (Fig. 1 presents the two garment types). Garments have been produced to create a standardized fit across participants in each of the BMI categories: normal (18.5-25 Kg/m^2), overweight (25-29.9 Kg/m^2) and obese (>30 Kg/m^2) [11]. Garments had a -12% difference to the chest measurement at sternum level as calculated from the three dimensional body scan.

Fig. 1. Male vest garment (left) and the female bra garment (right). Within the images 1 is the Shimmer device placed within a pocket on the front of the garment. 2 depcits the location of the TE.

Garments have two integrated TE placed just below the chest muscles at sternum level. These electrodes are then connected via standard snap connectors to a Shimmer device (Shimmer 2R, Realtime Technologies, Dublin, Ireland) which is also equiped with an ECG daughter board . This configuration allows for the detection of a one lead ECG from which heart rate can be detected.

3 Experimental Procedure

Five healthy older adults (male n=2, female n=3) volunteered to take part in the study. Individuals were recruited from local walking groups to participate within the Design for Ageing well project [12]. Participants were selected as body shape and size representatives for their BMI categories as the best match to the national average. Before beginning the study all subjects were provided with participant information sheets and completed a physical activity readiness questionnaire (PAR-Q). Participants were free of cardiovascular, pulmonary and metabolic disease as reported by the PAR-Q. The average age of the participants was 65 ± 2.5 years. The work was carried out in accordance with ethics approved by the local University ethics committee.

Participants were instructed to carry out a number of tasks in a predefined sequence whilst wearing the garment prototype. In total 7 postures were selected in order to cover a range of trunk and arm movements. These tasks where identified as they represent action primitives that would be present during a number of activities of daily living [13]. These are presented in Table 1.

Table 1. Posture and activities included within study. Postures were selected to cover a range of trunk and arm movements which represent activities of daily living [14].

Type	Task	Detail
Posture	Standing Base	Standing Comfortably, arms by side relaxed
	Sitting Base	Sitting comfortably, arms by side relaxed
	Trunk Rotation	Twist left to right
	Trunk Bending	Bend left to right
	Arms in front	Raise arms in front
Activity	Stand to sit	Sit to stand in static chair
	Walking Stairs	Walking up and down stairs at self selected speed

Static postures were held for 3 seconds before returning to the base standing posture. Walking up and down stairs and stand to sit transitions were performed at the participant's self selected normal speed. Postures and activities were explained and demonstrated to each participant prior to beginning the study. Each posture or activity was repeated. Data was recorded for 3 seconds pre- and post- task completion.

Two Shimmer wireless sensor platforms were used during the experimentations. One device was used to record a single lead ECG from the TE integrated in the skin layer garment. The second device was used to record a one lead ECG from two wet electrodes (WE) (Philips 40493) placed directly onto the skin within close proximity to the textile electrodes. Data was sampled at 200Hz and streamed via Bluetooth from each device to a PC. The PC had a custom created user interface, developed using BioMOBIUS 2.0 (TRIL Centre, Dublin), and allowed the recorded data to be saved to file for off-line processing.

A beat detection algorithm, based on the Pan-Tompkins approach[14], was created using Matlab 2009 (Mathworks Inc., Massachusetts). The number of R peaks detected by the algorithm within the ECG signal acquired from WE and TE was then compared with a gold standard measurement of manually counted R peaks from the WE.

Data was analyzed according to the Bland–Altman method [15]. The percentage difference between the two measurements was plotted against the actual number of R peaks counted from the WE. The difference between the two methods for each task was used to calculate the sensitivity, bias and standard deviation (SD) of the textile system. This allows the proportion of R peaks that were correctly identified by WE-peaks and TE-peaks to be quantified.

4 Results and Discussion

Results have highlighted how the custom fitted heart rate monitoring garments preformed during a number of predefined tasks. Fig. 2 presents an example of the one lead ECG data recorded during the standing base and walking stairs tasks. Increased movement of the TE compared to the WE is clearly visible within the recordings as indicated by a significant motion artifact present in the signal.

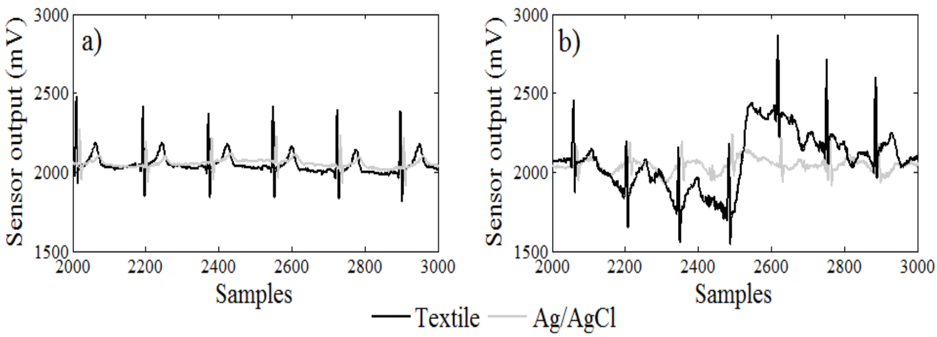

Fig. 2. Examples of ECG data recorded from a male participant during a) Standing base, b) Walking stairs tasks. Each graph shows data from TE (dark trace) overlaid on data from WE (light trace).

Table 2 provides the average sensitivity values for both WE and TE for each user during each task. WE achieved a mean sensitivity of 98.19% across all tasks. For TE the mean sensitivity for all users varied depending on the task being performed. As expected the base positions (standing and sitting base) had the highest sensitivity values of 96.87% and 95.08%, respectively. This was due to the low movement of the torso exhibited during these tasks.

Average sensitivity for TE was significantly lower during tasks which required movement of the trunk and limbs. This is particularly noticeable during tasks involving bending and twisting of the trunk. In these tasks TE achieved a low sensitivity of around 60-70%. This was likely caused by increased movement of and variations in pressure between the electrode and the body produced by movement of the trunk and limbs.

Table 2. Average SV of R peak detection based on the Pan-Tompkins algorithm with ECG data obtained from WE and TE compared to a manual count of R peaks gleaned from WE for each participant (n=5) during each task

Task	*Type*	*Standing base*	*Sitting base*	*Trunk rotation*	*Trunk bending*	*Arms in front*	*Sit to Stand*	*Walking stairs*
User 1	WE	100.00%	100.00%	98.86%	95.89%	100.00%	100.00%	95.45%
	TE	100.00%	100.00%	40.40%	84.24%	82.68%	65.12%	50.65%
User 2	WE	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	TE	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
User 3	WE	100.00%	97.30%	95.35%	95.14%	100.00%	97.37%	92.06%
	TE	100.00%	97.30%	66.40%	60.18%	75.65%	94.14%	49.03%
User 4	WE	100.00%	100.00%	97.78%	100.00%	96.67%	94.59%	90.06%
	TE	85.86%	78.13%	13.33%	9.77%	0.00%	53.65%	10.47%
User 5	WE	100.00%	100.00%	100.00%	100.00%	100.00%	96.41%	93.84%
	TE	98.50%	100.00%	92.65%	100.00%	100.00%	96.41%	71.89%
Average	**WE**	**100.00%**	**99.46%**	**98.40%**	**98.21%**	**99.33%**	**97.67%**	**94.28%**
	TE	**96.87%**	**95.08%**	**62.56%**	**70.84%**	**71.67%**	**81.86%**	**56.41%**

Tasks which involved dynamic movements such as walking stairs also had lower sensitivity when compared to the base measurements. Sensitivity was lowest during the walking stairs task. This can be attributed to the increase of bodily movement during the activity being undertaken. This increase in bodily movement can be affirmed by correlation with the acceleration data simultaneously obtained from the Shimmer onboard 3 axis accelerometer as presented in Fig. 3.

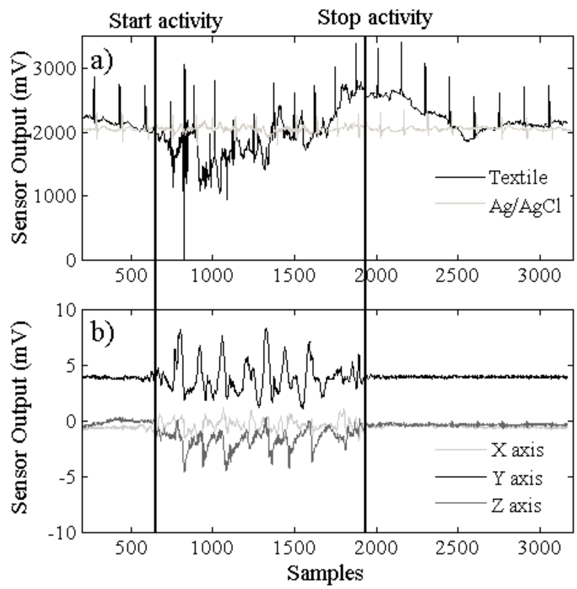

Fig. 3. ECG and corresponding raw three axis accelerometry data recorded from User 1 during the walking stairs task. The start and end of the task are annotated. a) ECG data recorded from TE (dark trace) and AG/AgCl electrode (light trace) and b) acceleromter data recorded from 3-axis accelerometer.

The mean percentage difference between TE-peaks and the manually count from WE for all tasks was 23.58%. The percentage difference calculations ranged from 3.13% for the standing base posture to 48.39% for walking up and down stairs. The Bland-Altman plot comparing TE with the gold standard is illustrated in Fig. 4. A range of TE detections were outside the average limits of agreement (mean ±1.96SD). This signifies poor stability of R peak detection from the ECG acquired from the TE during these tasks. Furthermore, this illustrates that the custom skin layers are not capable of making an accurate and reliable detection of R peak complexes during these tasks.

It must be noted, however, that the performance of the skin layers was not uniform for all participants. Most notably, User 2 had 100% sensitivity across all tasks. Conversely, User 4 had particularly low sensitivity in comparison to all other participants. This was particularly noticeable during the standing and sitting base measurements where User 4 had sensitivity measurements of 85.86% and 78.18% respectively in comparison to all other participants who achieved over 90% sensitivity.

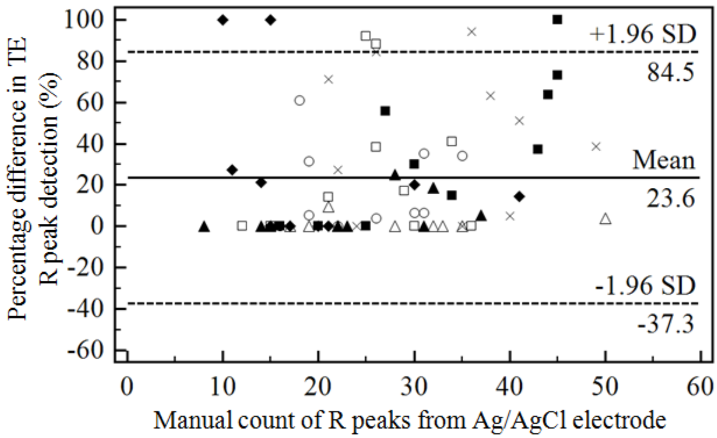

Fig. 4. Bland-Altman plot for comparison of R peak detection from five participants whilst carrying out the 7 identified tasks. Mean bias for all tasks is illustrated by the solid line. Limits of agreement, defined by 1.96 standard deviations above and below the bias, are shown by dashed lines. Tasks are represented by ΔStanding base ▲Sitting base ■Trunk rotation □Trunk bending ♦Arms in front ○Sit to stand and xWalking stairs.

This intra-user variability may stem from various sources. One possibility is that a subject's BMI may have an influence on the performance of the custom skin layer. This theory is supported by results from some participants with lower BMI having better performance than their counterparts. More experimentation is required to assess this hypothesis.

Furthermore, there may also be variability within the fit of the garments. Although all garments were custom fitted to provide a -12% difference from the bodily measurement at the sternum, some participants have exhibited changes in their weight during the time between measurements were acquired and the garments were produced. Therefore the garment fit may not be as standardized as initially perceived.

5 Conclusion

This study aimed to assess the performance of custom fit intelligent garments with integrated TE. In order to assess this, the reliability of R peak detection whilst carrying out a number of predefined tasks was assessed. Performance tests have shown that the custom skin layers previously detailed did not perform accurately whilst performing tasks which included movement of the arms and torso. The performance, however, did vary between subjects. Further work is required to identify the reasons why the system functioned accurately on some users and not on others.

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Multi-modal Non-intrusive Sleep Pattern Recognition in Elder Assistive Environment

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Abstract. Quality of sleep is an important attribute of an elder's health state and its assessment is still a challenge. Sleep pattern is a significant aspect to evaluate the quality of sleep, and how to recognizethe elder's sleep pattern is an importantissuefor elder-care community. This paper presents a novel multimodal sensing system to monitor the elder's sleep behavior with the pressure sensor matrix and ultra wide band (UWB) tags.Based on the proposed sleep monitoring system, the paper addresses the unobtrusive sleep postures detection and pattern recognition approaches, and the processing methods of experimental data and theclassification algorithms for sleep pattern recognitionare also discussed.

Keywords: Sleep Pattern, Elder-care, Pressure Sensor, UWB tags, Naïve Bayes Tree, Random Forest.

1 Introduction

Sleep is indispensable to everybody. As have been reported in Ancoli-Israel and Roth [1] that is consistent with other national studies, about one-third of people had some kind of sleep problem. Hence, the study of sleep pattern, much of which is through sleep recordings, has consistently been a hot research topic. Specially, sleep disorder is more serious in elder community. In an aging study of over 9000 subjects aged 65 and older, more than 50% of older adults reported the frequent trouble falling asleep, difficult waking or waking too early, or needing to nap and not feeling rested [2]. More seriously, sleep disorders have a cumulative effect on elders' physical and mental health, and usually put the older adult at greater risk for decreased physical functioning, problems with memory, increased risk of falls and mortality.

With the life expectancy of human increasing significantly, there are more elderly people living in the world today than they were 10-20 years ago [3], and the proportion of the elderly will grow to 25.9% and 14.6% respectively for the developed and developing regions by 2030[4]. In fact, there are many elder people in our community,

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because of age, infirmity, and memory loss or impaired judgment, who prefer to live alone but not give up their precious independence.

According to the requirement of the aging society, a simple and minimally invasive detecting system of the elders' sleep pattern should be developed to maintain their health and safety. Unfortunately, there are no convenient, unobtrusive and accurate ways to obtain the elder's body behaviors during sleep outside of a clinic.

Body movement is generally considered to be an important index in the analysis of sleep pattern shifts in sleep physiology [5]. The term 'body movements' can be described by body postures changing to/from a lying position, to turn from side to side, and to reposition the body while in bed. In the literature to analyze the distribution of behaviors during sleep [6], body movements were classified as minor movements (actogram signal or head leads artifact) and major movements (actogram signal plus head leads artifact). Major movements usually are associated with changes in body posture, involving the head, arms, torso rotations, any combination of upper and lower limbs, and any combination of limbs and torso rotations. So, given a time interval, the sleep pattern can be detected by the body posture. In this paper, we will consider the 5 typical postures, namely, left-lateral sleep (LLS), right-lateral sleep (RLS), supine sleep (SS), prone sleep (PS) and getting up (GU). These postures will be detected by a chaotic sensing approach, which adopts a matrix of pellicle pressure sensors deployed in the bed and 6 UWB tags embedded in the pajamas. By detecting the sleep postures, the authors try to recognize the elder's sleep pattern in a non-invasive means.

The key contributions in this paper include: i) Introducing multimodal sensors into sleep detection; ii) Presenting the detailed design of sleep detection system; and iii) Proposing a sleep pattern recognition approach based on pressure and position data.

The rest of this paper is organized as follows: section 2 summarizes the related work in sleep detection; in section 3, we describe the design of sleep detection system with pellicle pressure and UWB sensors; section 4 proposes the experimental method for sleep posture detection; section 5 presents sleep pattern recognition approach based on the postures, and also discusses the experiments analysis and performance evaluation; finally section 6 presents the conclusion of this paper.

2 Related Work

Many sleep sensing approaches have been proposed for assessing body behaviors in bed, in this section, we will describe some of the representative work on continuous sensing of body behaviors (movements) in bed.

The assessment of sleep-related motor disturbances is traditionally performed by overnight polysomnograph (PSG) to continuously record oractigraphy[7]. Although polysomnography, which includes EEG measurement, is a widely used and reliable method, the technique is rather complicated and both subject and examiner are seriously restricted [8]. With actigraphy, activity monitors are attached to a person's wrist or lower extremity [9, 10] to assess nocturnal activity. It is commonly used for long-term assessment, medical and behavior therapy in conditions such as insomnia and periodic limb movements during sleep (PLMS) [11]. Most of the actigraph models used in sleep studies can determine sleep and wake periods from the level of activity of the patient, but their algorithms only provide accurate sleep/wake periods if the patient provides bedtimes and get-up times.

Besides, accelerometers and RFID also have be used to assess movement in bed [12][13], but they place a burden on the subject because the patient has to wear them all the time.

Nowadays, there have been tremendous research efforts to apply UWB technology to the smart healthcare system. This can benefit the patient in chronic condition and provides long term health monitoring. Localization with UWB sensors is the most important area which can be required in many applications, such as indoor navigation and surveillance, detection and tracking of persons or objects, and so on [14].

As mentioned above, the previous solutions are not applicable for sleep detection at home in a non-invasive way, and this paper proposes an unobtrusive sleep posture detection system for elder-care, which is relatively and easy to be deployed in an ordinary bed without any special alteration.

3 Description of the Developed System

3.1 The Framework of SDS

The framework of SDS can be seen in Fig.1, and there are four levels in it, including physical sense level, data acquisition level, posture detection level, and service provision level.

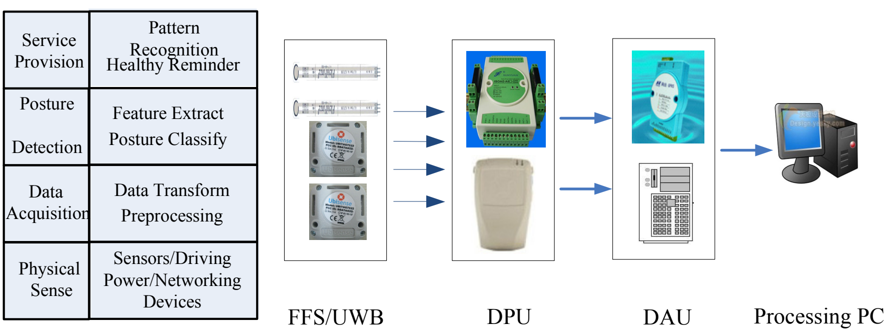

Fig. 1. The Framework and Main Components of SDS

Physical Sense: the level consists of a matrix of 32 pressure sensors and 6 UWB tags, which sense the body pressure and position respectively. In SDS, we chose a novel type of pressure sensor named FlexiForce. The FFS is ultra-thin, low-cost and flexible. To trigger the FFS-Matrix, we developed a direct-current low-voltage driving power unit (DPU). Concurrently, small UWB tags are applied in SDS, which can be carried anywhere on the body, and provide position accurately enough to determine dynamic sleep postures.

Data Acquisition: this level includes a Data Acquisition Unit (DAU) to process the analog signal and 4 UWB sensors (radio receivers) to calculate the location of UWB-signal transmitters (Tags). As seen in Fig. 1, DPU power the FFS-Matrix and transmits the analog signals as current, and then the DAU receives and transform these signals into digital data.

Posture Detection: this level is modularized software residing in the Processing PC, including three parts: the receiving module is a soft port to receive real-time digitized data from the DAU and synchronized data from UWB sensors; the forwarding module is to input the data into MySQL database for permanent storage and also feed the raw data into posture detection module, which is finally to preprocess the received data and analysis the elder's sleep posture using classification algorithms.

Service Provision: based on the sleep postures and their duration, we can infer the elderly user's sleep pattern, and evaluate the quality of sleep. On the one hand, the important health information will be fed back to the elder and his caregiver; on the other hand, the preferred sleep posture is usually recommended according to the elder's own disease [15], for example, an elder with coronary heart disease is generally suggested a right-lateral sleep posture, thus SDS will also provide necessary reminder to the elder when the sleep pattern is improper for his health. This part is under developing and we will report our progress in future.

3.2 Sensors Deployment

As seen in Fig.2, there is an "active sensing area" at the end of the sensor, which is a 9.53mm diameter circle. Meanwhile, known from common sense that the elder's body posture is mainly relied on his trunk, hence the FFS Matrix was deployed as seen in Fig.2, and there are two arrays to monitor the body pressure of back and hip separately. To ensure the accuracy, these two FFS arrays are fixed onto a flexible and rigid pad, and which occupies 2M by 0.75M, with sensor elements spaced 10 CM apart. The pad is placed on the bed under the coverlet and on the top of normal mattress, without any special installation requirement. Since FFS is ultra-thin and non-invasive, the elder will not feel uncomfortable for FFS Matrix and can be easy to accept the unobtrusive monitoring manner. Furthermore, we developed a 48-channel hub-like port to assemble so many wires connecting sensors, which is placed under the bed together with DPU and DAU.

Meanwhile, we innovatively introduce UWB technology into sleep detection, which has these features for the application in elder-care field, like—non-invasiveness, low power, non-contact remote operation, bio-compatibility, biofriendliness, etc. [16]. In SDS, the UWB positioning system is from Ubisense, and consists of 4 Ubisensors and 6 active Ubitags, and the deployment can be seen in Fig.3. The system has been chosen because it provides positioning accurately enough to determine sleep posture while at the same relying on a small Tag (38mm x 39mm x 16.5mm, 25g) that will not disturb the elder people during the sleep time, and we embed the 6 UWB tag in the pajamas on both sides from top to bottom, as seen in Fig.3.

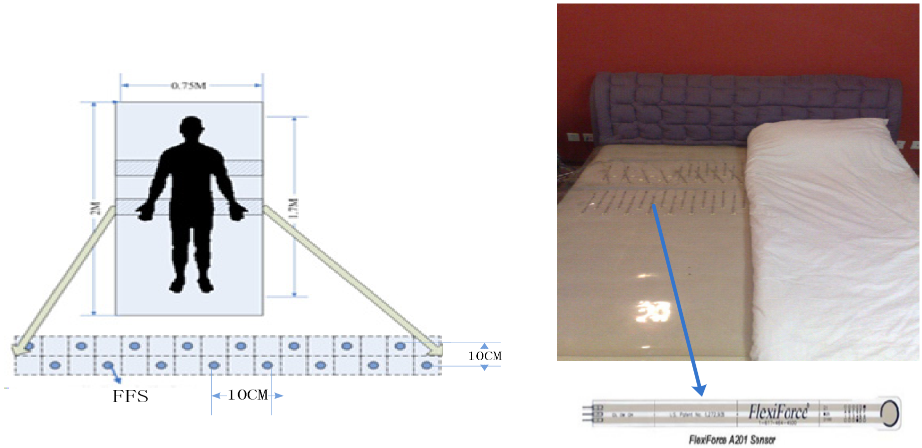

Fig. 2. The Deployment of FFS Matrix

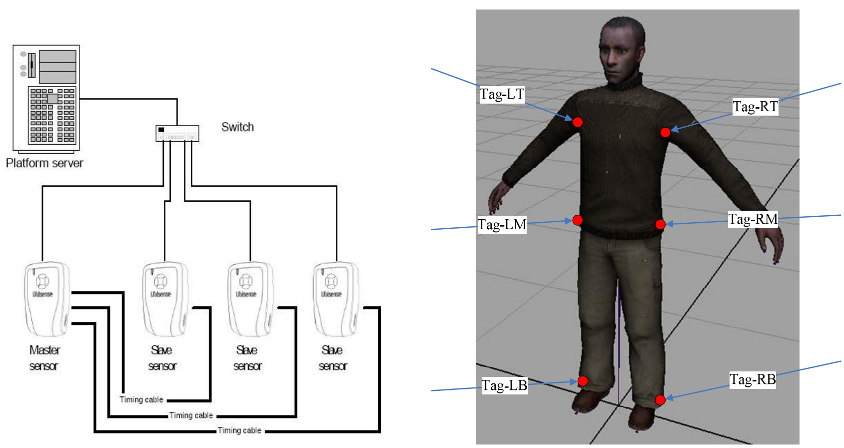

Fig. 3. UWB sensors and tags deployment in the SDS

4 Experiments Analysis and Pattern Recognition

Although we can use the pressure sensor and UWB tag to detect the sleeping posture separately, we try to improve the prediction performance and then combine these two sensing approaches and collect two kinds of data at the same time.

In this work, we just simply combine the attributes of two data sets to compose a new data. The combined data are with 48 attributes where the first 30 attributes are from the pressure sensor data and other 18 attributes of UWB data. CombinedData1 is composed of PressureData1 and UWBData1, and similar to CombinedData2. Two validations are applied as previous. To be compared with the previous results on pressure and UWB positioning data, the results of combined data are illustrated in the following two figures.

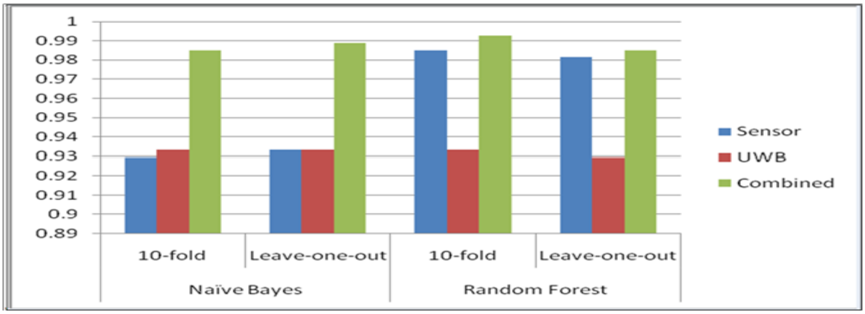

Fig. 4. Prediction Accuracy Comparasion among PressureData1, UWBData1 and CombinedData1

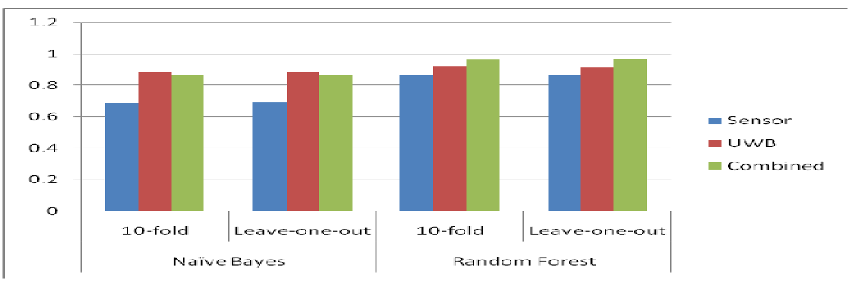

Fig. 5. Prediction Accuracy Comparasion among PressureData2, UWBData2 and CombinedData2

The Navie Bayes method treats all the attributes with the same weights and it is based on the assumption that all the attributes are independent in the test data set [17]. However, in our combined data sets, the first 30 attributes and the last 18 attributes are in two attribute classes. If all of these attributes are treated the same and the relationship among them is not considered, the information about the attributes is igored in the Naïve Bayes method. In this situation, the combined data maybe could not achieve better results than the data set separated.

The results of the experiment also reveals it. In Fig. 4, the accuracies of combined data are higher than the prediction accuracies of others, while in Fig. 5 the predict accuracies of UWB data are higher than the results of combined data. It indicates the Naïve Bayes method is not stable and reliable in simply-combined data sets.

There is no assumption of attribute independence in Random Forest method. It estimates the importance of attributes in determining classification and provides an experimental way to detect attributes relationship [18]. The Random Forest method in this combined data can identify the relationship among the first 30 attributes and that among the last 18 attributes. The results also indicates the preformance of Random Forest. In Fig. 4 and Fig. 5, the prediction accuracies of Random Forest are both better than the results on the Sensor and UWB data.

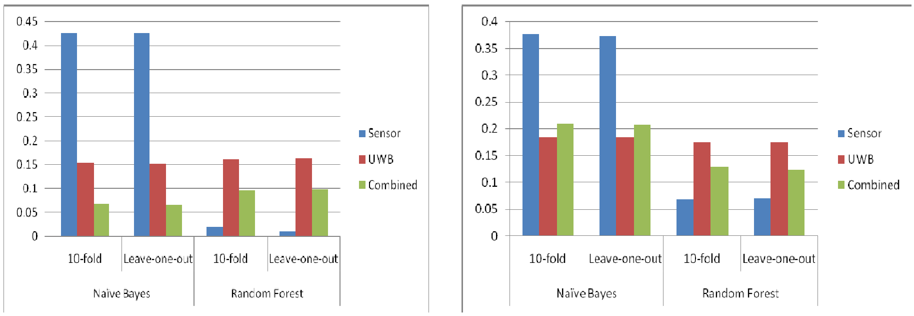

Fig. 6. RMSE of Two Prediction Results(Left: 3 Subject Data; Right: 10 Subject Data)

Fig. 6 is the RMSE of these two experiments. It indicates the stability of prediction results on different sleep postures. Fig.6 shows the Naïve Bayes and Random Forest on combined data sets are both able to get stable results on different sleep postures. The improvement of accuracy does not decrease the stablity of prediction results.

5 Conclusions and Future Work

This paper proposed an unobtrusive sleep pattern recognition system based on a multimodal approach using ultra-thin pressure sensor matrix and UWB tags. We presented the design of sensors deployment and the implementation of the sleep behaviors detection system. Moreover, based on the experiments, we discussed the data analysis and evaluation of the system and the result proved that the proposed solution is a promising way to monitor the elder's sleep postures and recognize his sleep pattern. In the near future, we will detect more specific postures for accurate sleep pattern recognition. Concurrently, the detection of the abnormal behaviors in bed will be another interesting direction and we also plan to invite some elders to evaluate the real benefice of the system.

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A Non Invasive, Wearable Sensor Platform for Multi-parametric Remote Monitoring in CHF Patients

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Abstract. The ageing of European population is now requiring novel solutions that help the healthcare systems face the new challenges. Novel monitoring solutions, combining state-of-the-art technologies will take a main role in the new healthcare models. In the present paper a prototype of an implemented non-invasive, wearable sensor platform for Congestive Heart Failure (CHF) patients is shown and described. The platform monitors all the required parameters from sensors, collects and processes the data in a mobile platform and sends the data to a server.

Keywords: Wearable sensor platform, Congestive Heart Failure (CHF), Multi-parametric monitoring, Electrocardiogram (ECG), Skin temperature, Sweat index, Activity recognition, Energy Expenditure.

1 Introduction

European healthcare models are facing important challenges due to the ageing of population and the increment of the number of patients with cardiovascular diseases, specifically, patients with congestive heart failure (CHF) [1]. These models, in which limited resources face an increasing need, should not only focus on disease treatment but also on disease prevention in order to reduce the number of hospitalizations and professionals devoted to patients, while improving the quality of the healthcare by means of a continuum of care in home, nomadic or hospital environments.

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This ambitious goal requires the use of state-of-the-art technologies that provide accurate and long-term health monitoring in a transparent way, i.e. avoiding invasive devices. Along with this, all the data obtained from patient monitoring need to be also combined and interpreted in order to build a physiological model for proper clinical diagnoses and by means of a seamless integration with the hospital workflow.

There have been previous efforts in CHF patient monitoring solutions. A recent meta-analysis presents several studies related to remote monitoring for CHF disease [2]. However, all of them present several limitations. Either they offer only at home devices or do not take into account parameters that can be relevant to CHF crisis detection, as skin humidity or ST segment shift with heart range changes. Therefore, a necessary previous step is to carefully choose the relevant parameters for CHF patients' care. A literature research was performed resulting in a long list of parameters, which were classified in short-term and long-term together with its relevance as potential risk factors. The present solution focuses on the short-term parameters: electrocardiogram (ECG), potassium blood content (obtained from ECG), average energy expenditure evaluation through activity recognition, skin and ambient temperature, sweating and ambient humidity. This solution differs from other remote monitoring systems for healthcare as it is specifically designed for CHF patients [3].

The objective of this work is then the design and implementation of a non invasive, wearable solution for continuously monitoring of the relevant parameters of CHF patients. This solution comprises the components that are in charge of concentrating the data, extracting the proper features and sending them to the hospital servers.

2 A System Description

The wearable platform comprises two different straps: one placed at the chest, which collect ECG, skin temperature, sweat index and acceleration data and a second one at the thigh collecting extra acceleration data for accurate activity recognition.

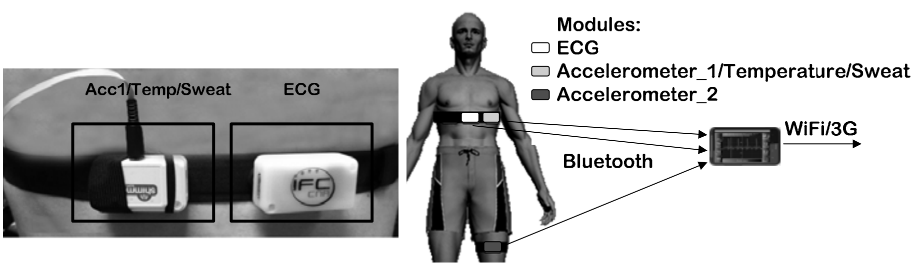

Fig. 1. Diagram and prototype implementation of the wearable sensor platform

Fig. 1 shows a scheme of the system. The modules collect the parameters from sensors and send the data to a mobile platform by means of Bluetooth connections. Bluetooth is a proper solution for sensor communication as most mobiles integrate it and it offers higher data rate than Zigbee. Bluetooth capabilities for sensors are provided by Shimmer modules, which are an adequate choice as they provide internal accelerometers together with standard digital (I2C, SPI) communication buses for new potential sensors [4]. They also offer high storage capacity by means of a 2GB SD card, small size and good autonomy because Bluetooth connections in this solution perform under the store-and-forward principle. Data is saved for a certain amount of time in a flexible way (ranging from real time communication to 60 minutes storage) and sent when the mobile platform asks for the information.

2.1 Electrocardiogram Sensor Platform

The wearable chest strap incorporates a compact device designed for continuous monitoring of ECG as shown in Fig. 1. The Shimmer based-platform includes ECG sensing device, signal conditioning, SD card and low-power Bluetooth module.

The light weight (~100 g) and compact form factor of the sensor makes it very suitable for physiological sensing applications. The electronic board and his enclosure was redesigned to be easily plugged on the common cardio-fitness chest straps (i.e. Polar®, Adidas®), which are fully washable and guarantee an optimal and comfortable contact with the thorax for a long time, adapting itself to the body shape. The belt includes two biocompatible, dry electrodes applied directly to the patient's skin for single-lead acquisitions without skin preparation, gels, or adhesives. The signals are analogue-to-digital converted with 10-bit accuracy and the output signal range is adjustable from differential (−3 V to 3 V) to single-ended (0 V to 3 V). Actually the firmware of the microcontroller tested adopts a sampling rate of 100 Hz, but it can be easily changed acquiring the signal until more than 1000 Hz. It uses an appropriate interrupt management of data for real-time streaming or storage on SD card. Moreover it is able to download the data from SD card to smart-phone.

2.2 Skin Temperature and Sweat Index Sensor Platform

Skin temperature and sweat index parameters are extracted by means of the Sensirion SHT21 digital sensor [5]. This sensor is suitable choice for temperature and sweat measurements, as it integrates both a temperature and a humidity sensor. In addition to that, the size of the sensor, its accuracy and its low power consumption makes it an adequate solution for wearable, battery-powered platforms. The temperature and humidity are measured with 0.3ºC and ±5%RH accuracy, respectively. The sensor power consumption is 1mW and 1.2µW in active mode and sleep mode, respectively.

In this solution, the sensor is placed in contact to the skin, in a stable position at the patient's armpit so that accurate measurements of temperature and sweat index can be obtained. On the other hand, the sensor is controlled by means an I2C communication protocol. A 4-wire bus connects the sensor to the Shimmer device. The firmware of the Shimmer takes temperature and humidity samples every 5 minutes as specified by doctors. Later on, samples are combined with the first accelerometer data in a single data packet and sent to the mobile platform when required.

2.3 Activity Monitoring Sensor Platform

The activity monitoring module utilizes data received from the sensor platform to identify the patient's current posture/activity and calculate the average energy expenditure expressed in the standard metabolic equivalent (MET). The method utilizes two accelerometers, one attached to the patient's chest and the other to the thigh, as well as skin temperature and heart rate information.

Activity recognition is performed with an overlapping sliding window method. We configured the Shimmer accelerometers to measure the acceleration with 50 Hz frequency. This means that we receive around 50 acceleration measurements along three perpendicular axes x, y and z every second for every accelerometer. We split this stream into 2 second windows, each of which contains around 100 measurements. The activity is recognized for each window.

The activities are recognized by a classifier trained by a machine learning algorithm. We limited our activity recognition model to recognizing the following activities: standing, walking, running, sitting, lying, on all fours, kneeling, cycling and transitions between these activities.

The raw acceleration values in each window are first transformed into attributes forming an attribute vector, which is then fed into the machine learning algorithm to train a classifier. New data are also transformed into attribute vectors and fed into the classifier, which recognizes the activities. Attributes which are used for classification, are divided into two groups: statistical attributes (average, minimum, maximum, variance, difference between minimum and maximum, correlation, orientation) and frequency domain attributes (frequency, energy) [6].

The energy expenditure estimation approach is methodologically similar to the activity recognition. The raw acceleration data are processed into an attribute vector for each time window of 10 seconds. The attribute vector is used to train a regression model for the task of human energy expenditure estimation in MET.

The attributes for the human energy expenditure regression model consist of (i) attributes derived from the acceleration, (ii) heart rate and (iii) skin temperature. The attributes derived from the acceleration were partially adopted from [7] and partially developed by us. Our original attributes are (i) the adopted attributes, but with the gravity subtracted; (ii) acceleration peak counter and summation of the peak values; and (iii) the recognized activity. The recognized activity is either the most prevalent activity in the window or transition if less than two thirds of the window contains a single continuous activity. This helps capture the movement dynamics.

2.4 Data Gathering Mobile Platform

The sensors are wirelessly connected to a smartphone by means of a low profile communication protocol at this stage. The use of a smartphone has several advantages. It can be carried by patients and so it permits their mobility. It is also a familiar device and guarantees that the patient will indeed have the device with him. In addition, the processing power of the smartphone and autonomy represents a nice compromise. Therefore, the smartphone is a satisfactory and simple solution with a small learning curve for patients and their families.

The smartphone can be simultaneously connected to all the sensors or in parallel communication alternating. It could also use its own internal sensors for acquiring further data (for example GPS for locating the patient in need of intervention).

On the other hand, sensors send readings with a wide range of sampling rate, from less than 1Hz (temperature) to 500Hz (ECG). High sampling rates drains the smartphone processing capacity and reduces its autonomy, so feature extraction algorithms to process and reduce the amount of data will be included. The smartphone can also check the integrity of collected data. Artifact and noise removal algorithms can be applied because they are fairly undemanding of smartphone processor power.

Finally, the mobile platform is a fully standalone solution which synchronizes data with a central server in user defined parameters. The timestamp, triggers and content of the synch are defined in a "rule engine", which allow for dynamic change, depending on the user's needs.

3 Results

This section shows the results of the CHF patient monitoring sensor platform.

3.1 ECG Monitoring Sensor Platform Results

To test the performance of the proposed system 4 healthy volunteers were enrolled age 30 ± 3 in the study. ECG was acquired from 2 freely moving nurses at work and 2 subjects at bedside for 3 hours. All the subjects wore both the developed chest strap with the smartphone and the clinical holter ELA. In Table 1 are reported the technical features of both devices.

Table 1. Features of the chest strap and the holter ELA

Technical features	ECG Chest strap	Holter ELA
Acquisition sampling rate:	100 Hz	1000 Hz
Resolution A/D:	10 bit	15 bit
Dimensions:	50 x 25 x 23 mm	97 x 54 x 23 mm
Weight:	~100 Grams	~300Grams
Power supply:	3V Li-ion battery 450mAh	1.5V alkaline battery
Data Transmission:	Bluetooth/802.15.4/SD Card	SD Card
Leads:	One	Three

As reported in Table 1, the main changes are due to the sampling rate i.e. ECG chest strap were sampled at 100 Hz, while ELA data were sampled at 1000 Hz. Moreover also the data transmission, the number of leads and dimensions are different. Applicability of the ECG chest strap in a clinical setting is now under investigation. Indeed, a specific study is in progress to validate the use of the system on cardiac inpatients within the Institute of Clinical Physiology of Pisa. In the first part of the study the data were collected from simultaneous ECG recordings obtained by our system and the ELA holter. The resulting waveform confirmed the signal quality was comparable to that captured using the ELA holter.

Moreover ECG chest strap provided readable signal for more than 95% and 99% of the time of acquisition while the subjects where on working and lying supine at bedside respectively. In the second part of the study we focused on the capability of the system to extract the features of cardiac rhythm. The high correlation between the two trends indicates a correct estimation of RR interval and of the average beat-by-beat heart rate from the ECG chest strap as shown in Fig. 2.

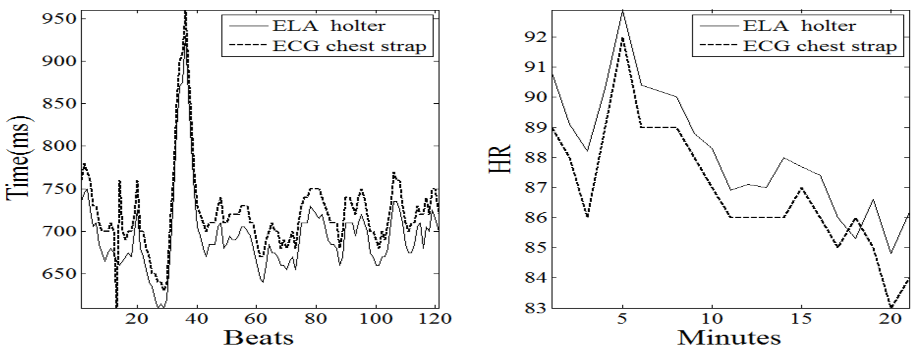

Fig. 2. Comparison between ECG chest strap and ELA holter of tachogram and heart rate, respectively

In order to process and identify further ECG parameters as P wave, T wave, and ST segment, a template matching algorithm technique was applied. The technique relies on the use of a basis template to identify relevant features. Mean ECG cardiac cycle is extracted as matching templates from the ECG chest strap and holter ELA raw data. Their comparison allowed high correlation to be gained, although further analysis is in progress to identify and analyze P, T and ST segments.

3.2 Activity Monitoring Sensor Platform Results

The activity monitoring consists of the activity recognition and the estimation of human energy expenditure. Machine-learning algorithms used to train models for both modules are implemented in the Weka machine learning suite [8].

For the activity recognition we have evaluated multiple classifiers trained using different machine-learning algorithms: Naïve Bayes, C4.5 decision tree learner, Random Forest and Support Vector Machine (SVM). The upper two rows of Table 2 show the classification accuracy (CA) for the selected machine learning.

The results show that Random Forest, which trains an ensemble of decision trees, is the best algorithm for activity recognition. A detailed inspection of the recognition with Random Forest shows that sitting was often confused for standing, and cycling for walking. Both problems are not surprising given the nature of the activities and accelerometer placement, but they are fortunately not overly problematic from the perspective of energy expenditure estimation.

The estimation of human energy expenditure was tackled by training a regression model. For the evaluation and selection of the most accurate model, four regression models were trained. These are Linear Regression (LR), Support Vector Regression (SVR) with linear kernel, Fast Decision Tree Learner (REPTree) and M5 Rules, which induce rules with linear functions in the consequent. The lower two rows of the Table 2 show the results of the trained models expressed in relative absolute error (RAE). The models are able to estimate energy expenditure for all the activities.

Table 2. The upper rows present the classification accuracy for the activity recognition task according to the algorithm. The lower rows present the relative absolute error of the regression task in energy expenditure according to the algorithm.

Algorithm	**Naïve Bayes**	**C4.5**	**Random Forest**	**SVM**
Activity Recognition (CA)	69.5	70.1	**80.3**	75.8
Algorithm	**LR**	**SVR**	**REPTree**	**M5Rules**
Energy Estimation (RAE)	28.3	23.43	**21.68**	27.7

We can conclude from the results that the REPTree is the best machine-learning algorithm. However, the disadvantage of this algorithm is poor interpolation and extrapolation, since the regression tree it trains contains a number of fixed MET values in the leaves, and the tree can only estimate the energy expenditure to be one of those values. The second best algorithm was selected for the final regression model. The advantage of the SVR algorithm is that the model it trains is simpler (a linear function) and thus less likely to overfit to the training data.

An analysis of the results of the trained regression model showed a decrease in overall accuracy is caused by energy estimation of activities running and cycling. This problem was tackled by adding additional classifiers used only to estimate energy expenditure for the problematic activities. We then combined the complete classifier with the per-activity classifier. The complete classifier was used whenever possible and the per-activity classifier in the case of cycling and running. The composite classifier returned mean absolute error of 1.4 MET and relative absolute error 20.5%.

3.3 Temperature and Sweating Monitoring Sensor Platform Results

Both temperature and sweating index parameters are required to be monitored every 5 minutes for a long period of time. However, the platform was tested at a higher rate, every 20 seconds, in order to check not only the sensor performance but also the autonomy of the temperature/humidity sensor+Bluetooth Shimmer module.

Fig. 3 shows the results of a 10 hour test in two different scenarios. From 0 to 9 hours, the volunteer performed normal activity: sit down, walking, etc., from 9 to 10 hours the volunteer performed moderate activity that resulted in sweating. It can be observed in Fig. 3 that the results show a rapid change in temperature together with a noticeable increment on humidity. It should be also noted that although only ten hours of parameter sampling are showed, the autonomy of the platform exceeds 16 hours at 20 second sample rate for both parameters. This autonomy would be further extended if we stick to 5 minute sampling rate.

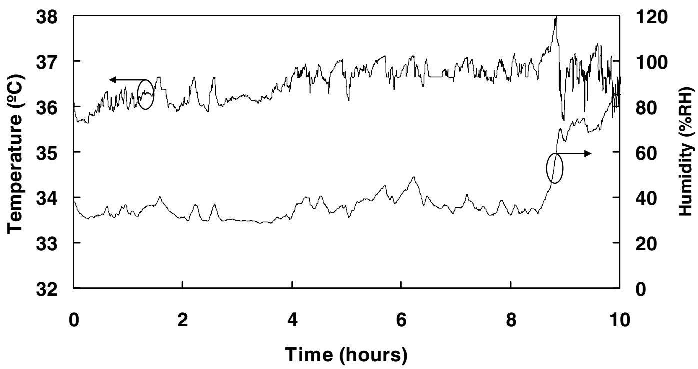

Fig. 3. Skin temperature and humidity test for ten hours of continuous monitoring and two scenarios: normal activity from 0-9h and moderate activity from 9-10h

4 Conclusions

A non invasive, wearable sensor platform implementation for CHF patient monitoring has been presented. The platform monitors accurately the ECG signal, data from two accelerometers for activity recognition and energy expenditure evaluation, skin temperature and sweating index. The platform communicates sensor parameters to a mobile platform by means of Bluetooth communications using the store-and-forward principle that preserves the platform autonomy. Results show that the combination of state-of-the-art technologies can address the challenges of the new healthcare models.

Future steps comprise the integration of collected data with those available in the Hospital Information System in order to build a physiological model of the patient (defined as Alter Ego).

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A Non-intrusive Monitoring System for Ambient Assisted Living Service Delivery

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Abstract. Automation of smart home for ambient assisted living is currently based on a widespread use of sensors. In this paper, we propose a monitoring system based on the semantic analysis of home automation logs (user requests). Our goal is to replace as many sensors as possible by using advanced tools to infer information usually sensored. To take up this challenge, an ontology, automatically derived from a model-driven process, firstly defines user-system interactions. Then, the use of rules allows an inference engine to deduce user location and intention leading to adapted service delivery.

Keywords: Pervasive Systems, Ambient Assisted Living, Model-Driven Engineering, Ontologies, Home Automation Services, Context-Awareness.

1 Introduction

Care for dependents is becoming a major social and economic issue for the next few years. In 2050, 30% of people from the european countries will be at least 65 years old [1], thus increasing the number of dependent people with chronic diseases. The number of potential caregivers can not evolve accordingly, so that home automation for ageing and disabled people is considered as an alternative solution to fill the gap, allowing one to facilitate or automate devices activation and to provide services tailored to the user needs: we talk about *Smart Home*.

Due to the miniaturization of electronic devices and their dissemination in the environment, smart home is no longer confined to the simple control of household appliances. This field of application is evolving more and more toward *Pervasive Systems* [2], where context-awareness is an important challenge. Indeed, knowing `who` is doing `what` and `where` is essential to adapt a "smart behavior", especially in the area of *Ambient Assisted Living*. The use of sensors distributed in the environment is the most commonly used solution to collect these contextual data. Two main methods can be distinguished, which can be coupled [3,4,5]: the use of cameras which is intrusive, and the massive deployment of sensors in the environment which implies a significant financial cost.

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Previous works from [6] highlighted the interest of monitoring activities based on home automation logs (user requests only) to limit the use of these sensors. Their monitoring system is based on a frequency analysis in which a service is considered as a repeating pattern over time. Based on the assumption of the existence of very regular activities, the goal was to automatically extract and to propose daily living scenarios to wheelchair-bound users with limited capabilities. However, this assumption is not always verified in practice, so that some potential scenarios are not proposed. For example, the user needs to switch on/off lights in rooms leading to the bathroom at night. This kind of interaction can be requested from time to time, in a non-regular manner.

In this paper, instead of a frequency analysis, we propose to use a semantic analysis of each home automation log to interpret service activation at a given time. In this perspective, it is possible to provide the user adapted services without any training steps and using as few sensors as possible. To take up this challenge, we first propose to model user-system interactions and their semantics by means of an ontology (section 2). Then, the use of rules applied to ontology concepts and properties allows an inference engine to deduce user location and intention, leading to service delivery (section 3). Finally, in the context of a large scale deployment, we propose to derive automatically the ontology from a model-driven process developped in previous works (section 4). A real case study (section 5) presents the benefits of the entire work.

2 An Ontology for User-System Interaction Modeling

Based on description logics, the ontology described above models the semantics underlying interactions between one user and his environment. As it is not possible to distinguish who activates a switch, we assume that the `user stands alone`. Obviously, our work should fit the need of a multi-user application, provided each log can be associated with an individual user id (e.g. services are requested from individual interfaces).

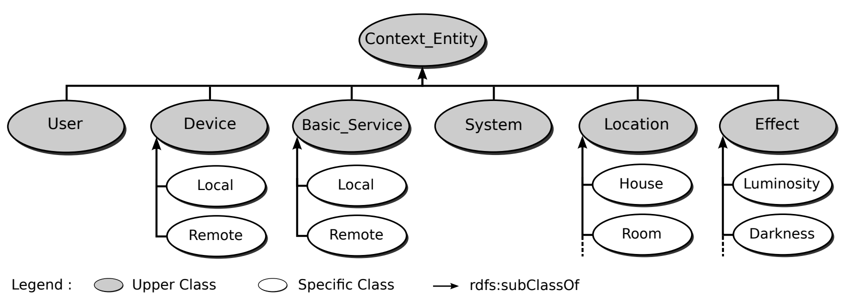

Fig. 1. Excerpt of the ontology taxonomy (TBox)

As shown in figure 1, the ontology is made of six fundamental concepts:

- `User`: someone who interacts with his environment using spread devices
- `Device`: resource activated by user i) remotely or ii) from the same room

- `Basic Service`: directly provided by both local and remote devices
- `System`: interface to collect interactions composed of devices and services
- `Location`: part of the environment that can contain devices and users
- `Effect`: effect of services activation on the environment (e.g. luminosity)

This ontology is a useful support to achieve supervision[1] using as few sensors as possible. From the way the user interacts with his environment, we seek to infer his *location* and his intention related to the *effect* produced by services activation. Knowing where the user is and what is his intention, it is then possible to lead to service delivery. This is made possible by the formal semantic of description logics underlying ontologies, but also by rule-based reasoning capabilities.

3 From a Non-intrusive Monitoring to Service Delivery

User tracking is an important context-awareness process, from which location can be inferred. In addition to ontology concepts described above, we add semantic relationships to link them. Figure 2 (left side) shows part the ontology terminology (*TBox*) for user location. The `Door` concept is defined with exactly two links `isBetween` towards two concepts `Room`. Given this logic representation, rules are expressed to infer properties such as `isLocatedIn`, `isEntering` and `isLeaving` following basic services activation. Consider for instance the rule 1 from table 1: a user *?u* who is using a local activation device *?d* which stand in room *?r*, is himself in this room.

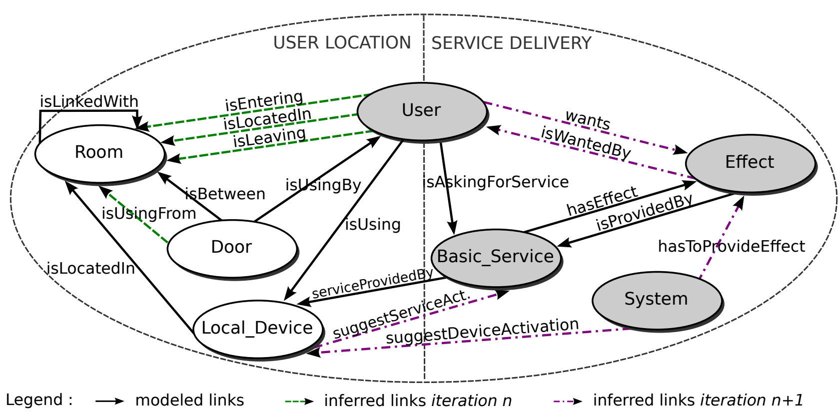

Fig. 2. Ontology (excerpts): user location (left side) and service delivery (right side)

Given the user location, it is then possible to deliver services based on the effect concept: when a user asks for a service, he knows that this activation will have an effect on his environment. Basic services are linked with effect (`Luminosity`, `Darkness`, `Heat`, `Quietness`, etc.) through the `hasEffect` property (cf figure 1, right side). The user intention can thus be inferred from this

[1] By supervision, we mean not only monitoring, but also service delivery.

Table 1. SWRL rules for user location (1,2,3) and for service delivery (4,5,6)

N°	Name	SWRL expression *(Semantic Web Rule Language)*
1	isLocatedIn	LocalDevice(?d), Room(?r), User(?u), isLocatedIn(?d, ?r), isUsing(?u, ?d) → isLocatedIn(?u, ?r)
2	isLeaving	Door(?d), Room(?r), User(?u), isUsing(?u, ?d), isUsingFrom(?d, ?r) → isLeaving(?u, ?r)
3	isEntering	Door(?d), Room(?r1), Room(?r2), User(?u), isBetween(?d, ?r1), isBetween(?d, ?r2), isLeaving(?u, ?r1), isLinkedWith(?r1, ?r2) → isEntering(?u, ?r2)
4	wants	BasicService(?b), Effect(?e), User(?u), hasEffect(?b, ?e), isAskingForService(?u, ?b) → wants(?u, ?e)
5	suggestDevice-Activation	BasicService(?b), Device(?d), Effect(?e), Room(?r), System(?s), hasToProvide(?s, ?e), isLocatedIn(?d, ?r), isProvidedBy(?e, ?b), isWantedIn(?e, ?r), serviceProvidedBy(?b, ?d) → suggestDeviceActivation(?s, ?d)
6	suggestService-Activation	BasicService(?b), Device(?d), Effect(?e), Room(?r), System(?s), hasToProvide(?s, ?e), isLocatedIn(?d, ?r), isProvidedBy(?e, ?b), isWantedIn(?e, ?r), serviceProvidedBy(?b, ?d) → suggestServiceActivation(?d, ?b)

kind of property. Let's consider the rule 4 from table 1: the user *?u* who is asking for a basic service *?b*, wants the effect *?e* associated with it.

Coupling the user intention with location information leads to service delivery. A user who wants luminosity (e.g. `wants(User1, Luminosity)`), and who enters a room will be offered services allowing to increase luminosity in the incoming room. Service delivery is based on `suggestDeviceActivation` and `SuggestServiceActivation`, applied respectively on `System` and `Device` (cf rules 5 and 6 from table 1). The design of such an ontology has to be flexible to adapt to user needs and evolving environments. On the prospect of a large scale service deployment, we choose not to do this complex modeling task by hand, but to automate it by means of a model-driven process.

4 A Model-Driven Architecture for Ontology Design

In the context of ambient assisted living, we strongly believe that, in addition to the home automation expert, a non-expert - but someone who is able to properly consider the context of living with a disability (e.g. an occupational therapist, a family member) - must be included in the design process. We previously developed in [10] a model-driven flow for the design of assistive home automation systems. Platform independent modeling (*PIM*) are separated from platform specific modeling (*PSM*)[2], so that non-expert designers can focus on specification rather than on implementation. Using a domain specific language, they can model both *environment* and *interactions* to define respectively the context of use and the user needs, before automatically generating the control code[3].

In this paper, we propose to automatically generate an ontology with the same domain specific language. Figure 3 shows the supervision module that consists of several steps integrated in the existing design flow. In step 1', relevant model

[2] In accordance to the *Model-Driven Architecture* (MDA) specification [7].

[3] Experiments have been conducted to validate the assumption made above.

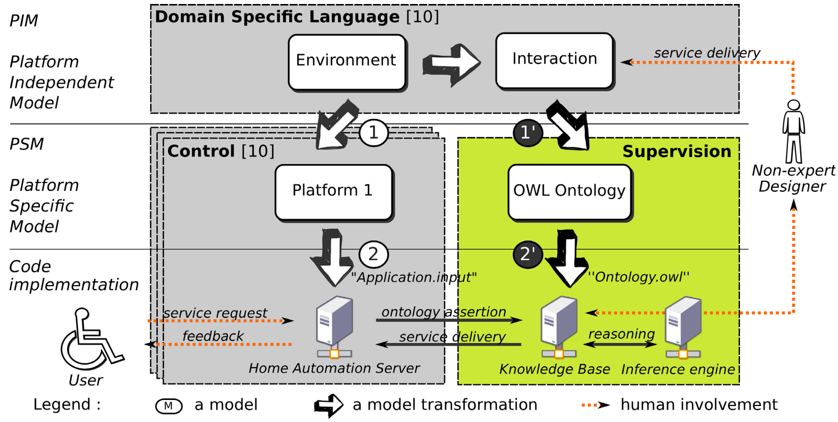

Fig. 3. User-centered design flow for the control and the supervision of smart home

concepts defined by this latter at *PIM* level are transformed into ontological concepts (*PSM* level). They have some basic information such as the layout of housing, devices parameters, but also services defined to consider user needs. Step 2' is about generating a knowledge base conformed to *OWL*, the most commonly used ontology language. The joint use of a model-driven architecture and ontology[4] makes sense to benefit from their respective advantages, thus leading to the definition of a complete control and supervision system for smart home. MDA and languages derived from this paradigm offer few means to formally interpret the semantic of models at runtime. On the contrary, ontologies make knowledge machine-understandable, by formalizing and by making explicit the semantic relations between concepts.

The implementation of our ontology as a non-intrusive supervision model is illustrated as follows. When the user asks for a service, it is first processed by the home automation server, before sending him back its execution result. The service request is also translated into an assertion in the ontology that represents and shares context information coming from various home automation platforms. Then, an inference engine has to interpret this assertion and to enrich the knowledge base with i) monitoring information that an home automation non-expert will be able to analyze to define new rules or new services and ii) service delivery on the user interface based on information previously inferred.

5 Case Study

To validate our approach, a person tracking application for monitoring and for dynamic service delivery is presented in this section. This case study is based on a real monitoring dataset recorded in the Domus smart home [11,12] from the

[4] The *Ontology Definition Metamodel* [8] is a specification to unify MDA and Ontology, making OWL conformed with the three modeling levels of the MDA specification.

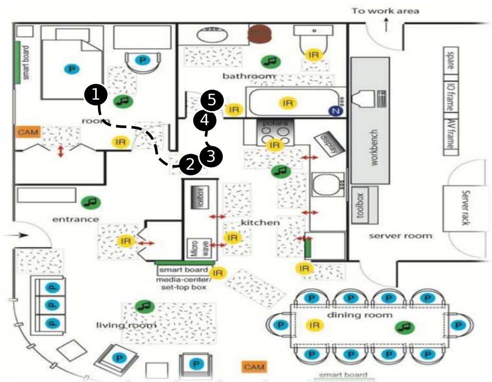

Fig. 4. A person tracking scenario in the Domus smart home, from [13]

Table 2. Dataset (excerpt) of series 1 / user 1 / day 2 considering devices activation (*: logs coming from user requests / °: logs coming from sensors)

N°		Time	ID	Name	Location	Service/State
1	*	8:56:17	5105	Light	Bedroom	SwitchON
2	*	8:56:26	0215	Door	Bedroom	Open
3	*	8:56:31	5101	Light	Kitchen	SwitchON
4	*	*8:56:35*	*5105*	*Light*	*Bedroom*	*SwitchOFF*
5	*	8:56:39	0215	Door	Bedroom	Close
6	*	8:56:44	0216	Door	Bathroom	Open
7	*	*8:56:46*	*5106*	*Light*	*Bathroom*	*SwitchON*
8	°	8:56:51	Fl01	T.ColdWater	Bathroom	Open state
9	°	8:56:54	Fl01	T.ColdWater	Bathroom	Close state
10	°	8:57:09	IR01	Infrared	KitchenSink	Close state
11	°	8:57:12	IR02	Infrared	KitchenOven	Close state
12	*	*8:57:12*	*5106*	*Light*	*Bathroom*	*SwitchOFF*

University of Sherbrooke (cf figure 4). It consists of data coming from sensors. Since our aim is to avoid the use of a maximum of sensors, we have converted some of these sensors logs by user requests on devices (cf table 2) when such devices can be remotely controlled[5]. We consider an excerpt of activities performed in day 2 by user 1 [13].

Step 1: `The user` (*user1*) `switches on the bedroom light`: "*[Log 1]: Light5105.SwitchON*" (log 1 from table 2). This log is introduced in the ontology through the following assertions[6]: "*[Assertion 1]: User1 isAskingForService SwitchON*" and "*[Assertion 2]: User1 isUsing Light5105*". Knowing that the ontology defines *Light5105* as a local activation resource located in *Bedroom*, and that this latter has a *SwitchON* basic service with *Luminosity* effect, rules 1 and 4 from table 1 can be applied. The inference engine execution allows then to

[5] As an example, *Fl01* is a flow meter mounted on the cold water tap of the kitchen sink. It sends an event when the tap is opened but cannot be remotly controled

[6] Each home automation log is divided into *isAskingForService* and *isUsing* properties.

lead to the following inferences: *[Inference 1]: User1 isLocatedIn Bedroom* and *[Inference 2]: User1 wants Luminosity.*

Step 2: The user now wants to go to the bathroom: after opening the bedroom door, `he switches on the kitchen light`: "*[Log 3]: Light5101.SwitchON*". Since this light is considered as a local activation resource, the following inferences are realized: *[Inference 3]: User1 isLocatedIn Kitchen* and *[Inference 4]: User1 wants Luminosity.*

Step 3: `The system proposes to switch off the bedroom light`. This proposition is based on the inverse effect property (e.g. *Luminosity* isInverseOf *Darkness*). The user being located in the kitchen, the system proposes to switch off lights in other rooms. In this scenario, this service is accepted by the user: "*[Log 4]: Light5105.SwitchOFF*".

Step 4: To go into the bathroom, `he asks for the door opening`: "*[Log 6]: Door0216.Open*". Considering this door linked with exactly two rooms with the *isBetween* property, rules 2 and 3 of table 1 can be applied. The user-door interaction allows the inference engine to extract the following information: *[Inference 5]: User1 isEntering Bathroom* and *[Inference 6]: User1 isLeaving Kitchen.*

Step 5: Finally, `the system proposes him to switch on the bathroom light` (log 7), from user intention and location previously inferred. These inferences are made possible trough rules 5 and 6 from table 1. Later, with the location information from sensor IR01, the system proposes him to switch off the bathroom light (as in step 3). This proposition is accepted by the user: "*[Log 12]: Light5106.SwitchOFF*".

The Domus smart home is equipped with infrared movement detectors, pressure detectors, switches contacts, and flow meters. This case study shows that the automatic inference of the user location by our model should limit the use to 37.5% of the sensors that has to be deployed to ensure this person tracking application. Sensors that can be removed are essentially switches contacts replaced by user requests and infrared movement/pressure detectors replaced by logic inferences. This case study can be generalized to all situations where the user moves from room to room, and needs the same services throughout its path (e.g. listening to music, watching tv, etc.). In a context of severe disabilities without economic constraint, quality of services may be preferred. If we decide to keep all sensors from this case study, this approach can improve the system dependability by sensors information redundancy (66.7% in this case study [7]).

6 Conclusion

The considerable increase of dependent people brings out important needs of monitoring to ensure a safe and secure independent living. In this context, this paper has presented a non-intrusive supervision model based on ontology for

[7] On table 2, the information from 8 sensors over 12 can be replaced/supplemented by a service request (see logs with *).

smart home. The supervision of such systems is not based on sensors use, but on the semantic analysis of logs recorded each time the user asks for a service. An ontology with associated rules allows the inference engine to extract information usually sensored. Finally, a case study based on a real monitoring data set validated our approach through a person tracking application.

This case study voluntarily uses very few sensors. A logic inference engine has to deduce the user location, thus replacing the use of movement detectors. However, to achieve a complete monitoring system over time, this approach should consider both user feedback and sensors whose information can not be inferred from home automation logs: information coming from biomedical sensors (e.g. blood pressure, core body temperature, etc.) or accurate information meters (e.g. temperature, luminosity, etc.). These latters could also be translated in assertions in the supervision model. Nevertheless, this approach allows the use of sensors to be limited, leading to a less intrusive and less expensive solution. Furthermore, it can improve the system dependability by redundancy of sensors information, especially important in ambient assisted living. In both cases, this approach provides a solution that may be more acceptable.

Service delivery is also an interesting contribution to allow users faster and easier access to services from their control interfaces [8]. A full-scale deployment is planned in two apartments of Kerpape MFRRC[9] to evaluate how it can assist patients in their everyday life.

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[8] Disabled persons with severe motion impairment (e.g. tetraplegia) can only control their home automation system by means of an automatic scrolling interface. In such restrictive situations, the selection of the desired service is very time consuming.

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Passive Sleep Actigraphy: Evaluating a Non-contact Method of Monitoring Sleep

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Abstract. Sleep problems can have a major impact on cognitive function, particularly in older adults who are also more likely to have a clinically diagnosed cognitive impairment. While several approved methods for sleep disturbance exist, most are not suitable for use within the abovementioned population. Often the reason for this is due to the symptoms associated with cognitive impairment or for the invasiveness of some sleep profiling methods. Developed from current sleep actigraphy techniques, this paper presents a non-contact alternative method for sleep profiling that is deemed to be more suitable for long term monitoring in the older population than current clinically approved techniques. This first evaluation has been conducted with a young control group in order to validate the approach. The results have demonstrated that based on the approach a random forest classifier using features calculated from optimally placed static accelerometers can produce a sleep/wake classification accuracy of 92%.

Keywords: Actigraphy, Classification, Passive Sensors, Sleep, Smart Homes.

1 Introduction

Aging has become a global phenomenon with the older population forming the world's fastest growing age group. Within this older age group, cognitive decline has been reported as being one of the most common ailments [1]. This ranges from simple forgetfulness to severe debilitating symptoms that significantly impair an individual's quality of life.

Cognitive testing is used to gauge an individual's mental status [1] and subsequently inform the level of care required. Nevertheless, mental status can be affected by several factors beyond the condition causing the primary cognitive decline. These factors can therefore impact upon the results of ongoing cognitive testing. Where this occurs it can lead clinicians to prescribe treatment believing that the new symptoms are a progression in the primary condition rather than a secondary cause. One such factor is sleep deprivation, a common problem in the target cohort [2]. By gathering information on an individual's sleeping patterns and using it to contextualise cognitive testing results, there is the potential for clinicians to be more informed and better able to provide targeted care to improve their patient's quality of life, for example, by reducing unnecessary prescriptions.

Currently there are several methods of profiling sleep. Of these, the gold standard is polysomnography (PSG) [3]. This is a multi-parametric test that enables a trained

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clinician to identify at what point in time a patient is awake or in a specific stage of sleep. While the information provided by this diagnostic tool surpasses the other methods presented in this paper, it does have a number of drawbacks, particularly for the target cohort. Generally, PSG is resource expensive both in personnel and equipment and requires expertise to interpret the data accurately. Furthermore it has been reported as a fairly uncomfortable procedure due to the number of body contact sensors that often forces people to sleep in positions they are not accustomed to [4]. As a result of these observed issues, several researchers have investigated alternative methods of monitoring sleep patterns.

1.1 Alternatives to Polysomnography in Sleep Profiling

One increasingly popular alternative to PSG is sleep actigraphy. Achieving widespread clinical approval in recent years [5] sleep actigraphy involves the use of a piezoelectric accelerometer embedded within a watch-like device to record a wearer's movement. Based on subsequent activity counts these devices determine if the wearer is awake or asleep. While diagnostically sleep actigraphy is not as sensitive as PSG, it is comparatively cheap, suitable for use within long-term studies, minimally invasive and is suitable for use at home [5]. For these reasons sleep actigraphy is often better received by the target cohort, however, this method still has its drawbacks. Most evident, the device will only work while worn which leads to two potential problems. Firstly, some individuals will not be comfortable wearing the device while they are sleeping. Secondly, in those with memory problems, the device may not be replaced after it has been removed for charging, bathing and so on [7].

Assuming that a clinician's interest is focused on nighttime sleep, this introduces the possibility of non-contact methods of sleep monitoring that will avoid the issues previously highlighted. Research to date has shown that such solutions exist predominantly within a research environment and typically adopt one of three approaches [6-8]. A load or strain gauge system placed under the feet of a bed used to identify movement vectors in the subject's center of gravity, the magnitude of these movements then being used to infer sleep/wake status as reported in [6]. A similar approach was reported in [7] using a matrix of pressure sensors, whilst in [8] a Doppler radar based system was used. To date, a literature review has not uncovered previous research that investigates the use of non-contact accelerometers. Such an approach may be able to take advantage of the extensive actigraphy domain knowledge in existence to validate this approach and could gain better clinical acceptance based on the success of traditional sleep actigraphy.

2 Materials and Methods

In the current study, passive sleep actigraphy was investigated as a method for profiling sleep and wake states in a young control population in order to validate the approach for future use in evaluations involving older users with a clinically diagnosed cognitive impairment such as mild stage dementia.

2.1 Subjects

In accordance with the ethical approval granted for the study and following acquisition of informed consent, participants were recruited from the University department's staff and postgraduate student pool. This paper presents the early findings from an investigation involving two participants; one male and one female, both aged between 20 and 29 years. Both participants were invited to record seven nights of data across a 14-night period.

2.2 Validation Measures

As previously discussed, an actiwatch is a clinically validated, lightweight and portable device suitable for long term deployment [5]. These features identified the actigraphy watch as the most suitable validation measure for labeling data collected in this study. A Philips Respironics Actiwatch Spectrum (referred to as the actiwatch from this point onward) containing a tri-axial accelerometer sampled at 32Hz with color sensitive photodiodes recording luminescence in the red, green, blue and white light spectrum was used. Data was captured and stored locally on the actiwatch in epochs pending transfer via USB to a computer running the Actiware software. To allow the continuous recording of data for 14-days, the internal storage capacity of the actiwatch dictated an epoch size of 30 seconds.

While the benefits of sleep actigraphy are clearly documented and the results are somewhat more objective than sleep logs [5], it has been noted that specificity rates with sleep actigraphy (i.e. the ability to identify waking periods, particularly after sleep onset) can be low [5], [11]. Therefore, the participants were requested to maintain sleep logs as a failsafe for the actiwatch.

2.3 Deployment of Shimmer Sensor Mote Accelerometers

This study utilised wireless kinematic sensors with tri-axial accelerometers attached to specific points on a bed mattress to identify the movements of the occupier during sleep. Six Shimmer v2.0r [12] sensor motes were deployed. Each unit recorded time stamped values of acceleration on the X, Y and Z axis sampled at 51.2Hz and transmitted samples in real time via Bluetooth to a nearby laptop running a LabVIEW (National Instruments) application designed to receive and store the data.

Each accelerometer was placed in line with the shoulders, hips and feet of the subject. These locations were selected as they provided an anatomical point of reference for accelerometer placement across all subjects. Furthermore, it was surmised these locations would be most sensitive to detecting movement when subjects were in the sleeping position. An iterative process of varying the sensor locations determined a distance of 10cm from the edge of the bed as the optimal position for signal quality and minimal impact on a subject's sleeping environment.

To maximise subject privacy, self-installation of the trial equipment was offered as a first option. To facilitate this each participant was supplied detailed instructions with technical support available by phone, email and home visit throughout the trial period. Once the equipment was setup, participants were asked to send some sample data and from this it was possible to determine if the accelerometers were correctly positioned.

2.4 Overview of Data Processing

The accelerometer signal consists of two elements; the acceleration of the physical device in its three dimensional space and the acceleration of gravity on Earth (9.81 m/s^2 or 1g). As this work focused on the physical movement of the accelerometer, it was necessary to separate out the two contributing signals. Due to the sensitivity of the accelerometer at different orientations to the ground as discussed in [9] only the Z axis data was used as input to further data processing.

Sleep actigraphy typically applies one or more methods of feature selection to summarise the source accelerometer signal into activity counts over a set period of time known as epochs. There are three common approaches to calculating the activity counts, two of which were investigated in the current study. The Time Above Threshold (TAT) method counts the number of times per epoch that the accelerometer exceeds a threshold, usually between 0.1g and 0.2g [5]. This will show the amount of time the signal exceeds the threshold, however, it will not present the details of the amplitude of any movement [5]. Digital Integration (DI) also known as Proportion DI calculates the area under the curve for each epoch. This technique shows the amplitude of any movement during the epoch, but not the duration [5]. The Zero Crossing method was excluded as it provides very similar information to TAT and is subject to high frequency noise that may be present in the accelerometer signal [5].

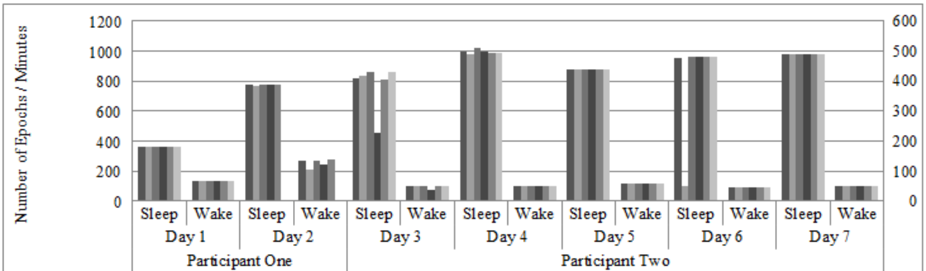
Previous work by Tilmanne *et al.* [10] evaluated classification approaches using the CHIME dataset [15], which includes actigraphic data on 1000 infants under the age of one. Part of this research involved the identification and extraction of discriminant features to use as inputs to different classification models. The feature subset extracted by Tilmanne *et al.* achieved sensitivity and specificity values up to 94.1% and 65.5% respectively with a bagged decision tree classification approach using PSG as the gold standard. Based on [10] four features were identified as the most discriminant and extracted from the TAT epochs:

1. The number of epochs in a 47 epoch centered window that have an activity superior to 2.025 times the mean activity of the file.
2. The standard deviation of recorded activity in a 25 epoch centered window.
3. The maximum epoch activity recorded in a 19 epoch centered window.
4. The sum of all the activities in a 37 epoch centered window.

In addition the source TAT and DI values were included in this dataset.

3 Results

Over the trial period, a total of seven night's actigraphy data was collected. Data was converted into epochs using TAT with threshold values of 1g, 1.5g and 2g and then collated by accelerometer position. This resulted in three datasets for each accelerometer providing 18 datasets in total. A breakdown of the data gathered showing the epoch count for each accelerometer by day is presented in Fig 1. This is then summarised in Fig 2, which shows the total average epoch count across the seven-day period for sleep and wake periods.



	Day 1 Sleep	Day 1 Wake	Day 2 Sleep	Day 2 Wake	Day 3 Sleep	Day 3 Wake	Day 4 Sleep	Day 4 Wake	Day 5 Sleep	Day 5 Wake	Day 6 Sleep	Day 6 Wake	Day 7 Sleep	Day 7 Wake
Top Left	364	137	774	266	821	102	993	102	874	117	955	88	975	102
Top Right	364	137	763	213	831	102	977	97	874	117	96	89	977	102
Middle Left	364	137	774	270	861	102	1023	104	874	117	964	94	977	102
Middle Right	364	137	774	242	456	76	998	102	874	117	964	94	977	102
Bottom Left	364	137	774	275	808	102	983	102	874	117	960	88	977	102
Bottom Right	364	137	0	0	863	102	984	102	874	117	964	94	977	102

Fig. 1. Summary of data collected shown by accelerometer position vs. day

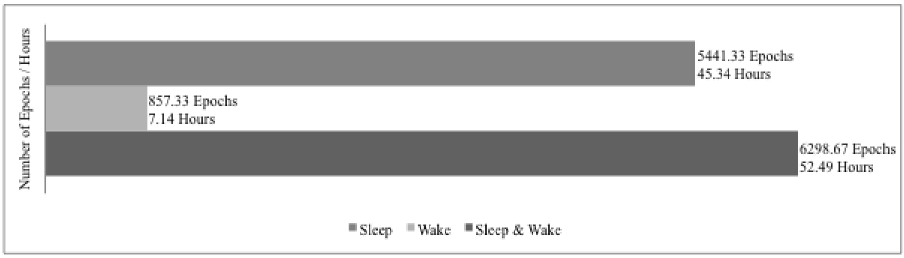


Fig. 2. Average of total data collected across all accelerometer positions and days

Previously, neural networks and decision trees have reported good results with sleep based actigraphy data [10]. A Neural network approach was not investigated in this study as they were deemed to require a larger number of training samples than was available. Decision tree methods on the other hand generally perform well with smaller datasets [10]. Six common decision tree classifiers employing a 10-fold stratified cross validation (CV) were selected from within WEKA [13] to evaluate the data. Sensitivity and specificity were calculated for each to determine:

- the most effective decision tree classifier from those tested.
- the optimal threshold for the TAT method.
- the most optimal accelerometer locations for evaluating sleep.

As with normal sleep actigraphy [10], the classifiers listed in Table 1 performed well for identifying when a subject was asleep with sensitivity values above 0.9. The greatest variance was observed in classifier's performance to determine when a subject was awake with specificity values as low as 0.22 being reported. Nevertheless, the random forest classifier performed significantly better than other models in all datasets achieving an average sensitivity of 0.92 and specificity of 0.77.

Table 1. Average classifier performance for all accelerometer positions by threshold

Decision Tree Classifier	T at 1g*		T at 1.5g+		T at 2g		Average	
	Sen	**Spe**	**Sen**	**Spe**	**Sen**	**Spe**	**Sen**	**Spe**
Best First	0.92	0.71	0.92	0.70	0.92	0.69	**0.92**	**0.70**
Naïve-Bayes Tree	0.91	0.70	0.97	0.33	0.91	0.66	**0.93**	**0.56**
J48 Graft	0.92	0.73	0.92	0.72	0.92	0.70	**0.92**	**0.72**
Random Tree+	0.93	0.55	0.93	0.56	0.93	0.54	**0.93**	**0.55**
Random Forest*	0.93	0.78	0.93	0.77	0.93	0.77	**0.93**	**0.77**
Simple Cart	0.92	0.71	0.92	0.70	0.92	0.70	**0.92**	**0.70**
Average	**0.92**	**0.70**	**0.93**	**0.63**	**0.92**	**0.68**		

* Indicates Best Performer in Row/Column; + Indicates Worst Performer in Row/Column

T, Threshold; Sen, Sensitivity; Spe, Specificity

Table 1 and Table 2 show a strong sensitivity performance across all classifiers and accelerometer positions, however, a threshold of 1.5g delivers a significantly poorer performance for specificity. Table 3 shows the full data summary for the random forest classifier, which was identified as the most effective method utilised. Here, sensitivity and specificity values are much closer, however, a threshold of 1g performs better than 1.5g or 2g.

Table 2. Average performence for all classifiers by accelerometer position and threshold

Accelerometer Position	T at 1g*		T at 1.5g+		T at 2g		Average	
	Sen	**Spe**	**Sen**	**Spe**	**Sen**	**Spe**	**Sen**	**Spe**
Bottom Left+	0.92	0.71	0.93	0.63	0.92	0.69	**0.92**	**0.68**
Bottom Right	0.92	0.74	0.93	0.69	0.92	0.73	**0.92**	**0.72**
Middle Left	0.91	0.71	0.92	0.63	0.91	0.70	**0.91**	**0.68**
Middle Right	0.92	0.75	0.93	0.66	0.92	0.73	**0.92**	**0.72**
Top Left	0.91	0.73	0.93	0.67	0.92	0.72	**0.92**	**0.71**
Top Right*	0.93	0.75	0.94	0.71	0.93	0.70	**0.93**	**0.72**
Average	**0.92**	**0.73**	**0.93**	**0.67**	**0.92**	**0.71**		

* Indicates Best Performer in Row/Column; + Indicates Worst Performer in Row/Column

T, Threshold; Sen, Sensitivity; Spe, Specificity

Based on the results of the random forest classifier with a threshold of 1g, it can be found from Table 3, column one, that accelerometers placed in the middle and top right positions on the mattress performed better than other positions.

Table 3. Results of random forest classifier for all positions and thresholds

Accel. Position	Threshold at 1g		Threshold at 1.5g		Threshold at 2g	
	Sen	**Spe**	**Sen**	**Spe**	**Sen**	**Spe**
Bottom Left	0.93	0.75	**0.93**	**0.73**	0.92	0.75
Bottom Right	0.92	0.77	0.93	0.76	0.92	0.77
Middle Left	0.92	0.77	0.92	0.75	0.92	0.78
Middle Right	0.93*	0.80*	0.93	0.77	0.93	0.77
Top Left	0.92	0.77	0.92	0.79	0.92	0.78
Top Right	0.94	0.81	0.94	0.81	0.93	0.79

* Indicates Best Performer in Row/Column; + Indicates Worst Performer in Row/Column

T, Threshold; Sen, Sensitivity; Spe, Specificity

4 Discussion

At the conclusion of the trial period each subject was asked a series of feedback questions to evaluate their experience. Initially the subjects were asked if they felt the Shimmer accelerometers disrupted their sleeping environment or behavior. Both subjects perceived no change to their typical sleeping position or behavior while the trial equipment was in place. Further questioning evaluated the user acceptance of the actiwatch. Both subjects indicated that they were aware of the actiwatch throughout the trial but that it was generally comfortable. It is interesting to note, however, that both subjects removed the watch after a few days and typically only wore it at night when recording data. Indeed, both subjects reported forgetting to replace the watch after bathing, changing clothes and so on, only remembering when they were preparing the trial equipment as they were going to bed. This finding further supports the benefits of researching non-contact methods of sleep profiling.

4.1 Evaluation of Results

As discussed in Section two, the actigraphy watch, supported by sleep logs, was used as the validation measure for this trial. Subsequently the agreement rate between these two measures was of interest. The sleep log maintained good overall agreement with only 124 (62 minutes) of the unique epochs evaluated being amended from sleep to wake. It should be noted that one participant did not maintain a full sleep log so not all actiwatch data could be verified. In general, the use of an actiwatch provides a simple and easy means of verifying the data from the test platform, however, its reported low specificity rates and over reporting of sleep [10], [11] does reduce its reliability as a gold standard. Using PSG as a validation measure in further work, the performance of passive sleep actigraphy could be directly compared to traditional sleep actigraphy for a more realistic evaluation of the test platform's potential. Furthermore, environmental conditions are known to effect sleep and as such further analysis should consider noise, light and temperature levels in addition to actigraphy data for potential improvement in sleep/wake classification.

Throughout the datasets there are several examples of where one or more accelerometers failed during the night. This was illustrated in Fig. 1 as a bar having a lower epoch count when compared to other accelerometers from the same night. It is surmised that the participants were not fully charging the accelerometers each day. This issue reduced the number of wake epochs being recorded in the study and most likely resulted in classifiers over-fitting sleep [10]. It is important that the capture of wake epochs is maximized to balance the overall dataset and improve classifier performance. Subsequently, options for ensuring the accelerometers are charged or augmenting their battery capacity will be investigated prior to future trials.

Focusing on the classification approach, while this work utilised a population specific model, (i.e. evaluated all the data collected from both participants by individual accelerometer positions) it would be of benefit to explore the potential for a person specific model in future work. This approach has yielded benefits in traditional sleep actigraphy as demonstrated by Van Someren [14] who showed significant improvements in classifier performance over a ten-day period. Nevertheless, research indicates that a minimum of seven night's data per individual was required to adopt this approach, which is beyond the scope of the current dataset.

The current results demonstrate that using the random forest classifier with a TAT threshold of 1g provides the best sensitivity and specificity performance. In the current configuration the highest performing accelerometers are located at the top right and middle positions. When compared to the initial questionnaire, it was noted that both subjects tended to sleep to the right hand side of the bed, which likely explains this result. This is an important observation when considering the potential for reducing the number of accelerometers required within the platform and will be investigated in ongoing work. Furthermore, from the various classifiers utilized, a random forest classifier that is based on an ensemble approach delivered the best performance. Further work should evaluate similar machine learning methods to determine if they are well suited to this type of classification problem.

In conclusion, with the understanding that this has been a small-scale trial with limited participants, the sensitivity and specificity findings with the usability outcomes are viewed as promising. This supports further evaluation of passive sleep actigraphy as a potential non-contact method of detecting disturbed sleep.

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A Semantic Plug&Play Based Framework for Ambient Assisted Living

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Abstract. The large scale deployment of ambient assisted living systems raises challenges related to the heterogeneity of the environments in which sensors, devices and services will be deployed, as well as the diversity of patients' needs and profiles. In these environments, each patient has a specific profile that influences the choice of interaction devices and requires particular services. The selection of required context-aware services affects the decision on the set of sensors that need to be installed. Moreover, even in one specific environment, new sensors, devices and services may need to be added due to the evolution of patient's needs. Therefore, a generic framework that is able to adapt to such dynamic environments and to integrate new sensors, devices and services at runtime is required. In this paper, we present a dynamic framework for ambient assisted living able to adapt to the non-uniformity of the deployment environments. The main contribution consists of a semantically driven plug&play mechanism integrated seamlessly with the reasoning engine so that all the entities present in the environment can be plugged and integrated in the reasoning process without interrupting the framework functionality. Our solution is based on the OSGi framework with the use of the DPWS standard and the semantic web.

Keywords: Ambient Assisted Living, Dynamic Environment, Service Oriented Approach, Open Service Gateway Initiative, Device Profile for Web Services, Semantic Web.

1 Introduction

Ambient Assisted Living (AAL) environments are usually evolving by the introduction or the disappearance of sensors, devices and services to respond to changes in patients' conditions. Deploying a generic assistive solution, able to adapt to such dynamic environments is very challenging. A Plug&Play mechanism needs to be developed to allow entities in the environment such as sensors,

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devices and actuators to be connected or disconnected from the system at runtime. These entities' dynamism should also be reflected in the reasoning process to perform the context understanding and to provide suitable services for patients on the adequate interaction devices.

In this paper we present our dynamic framework for AAL, based on the Service Oriented Approach (SOA), catering to the dynamism of the environment with a semantic plug&play mechanism. Using the Open Service Gateway initiative (OSGi[1]), the Device Profile for Web Services (DPWS) standard and semantic reasoning, this framework aims to provide context-aware services for a nursing home' residents in order to assist them in performing their Activities of Daily Living (ADLs) so that they can maintain their independence [1].

2 Related Work

Some work in the literature has contributed to the dynamism and adaptability of systems in pervasive spaces and AAL environments. Existing research on application polymorphism [2] and network selection [3] has helped on the portability of applications through different devices and on the network selection during device mobility. The dynamic integration of entities based on the use of a middleware and some semantic representation was introduced in a position paper by Helal et al [4]. Some work already exists allowing the discovery of, and the interaction with devices [5,6]. However, no semantic bindings are added to the devices in these approaches; thus, either it does not support any device selection or it is only based on the devices intrinsic characteristics without reasoning on the context. On the sensor part, semantic reasoning has been used in wide-area sensor networks to perform the sensor network self-configuration [7], however, there is not much work on sensors' Plug&Play and on the semantic binding of newly discovered sensors.

In our framework, we follow an approach similar to Helal et al [4] with the use of OSGi, DPWS and semantic reasoning. DPWS is a Web Service (WS) standard that allows entities in the environment to discover each other's presence on the network using a unified and standardized protocol [8]. Every entity is able to describe itself and all its services. DPWS uses WS-discovery for entities and services discovery and WS-eventing for service and event exchange. A specific driver [9] was specified to enable the DPWS communication through OSGi containers.

3 The Semantic Plug&Play Framework

Our Dynamic Service Oriented Framework for Ambient Assisted Living is based on the OSGi framework with the use of DPWS for the Plug&Play mechanism and Euler[2] reasoning engine for the semantic reasoning. The framework is composed of two OSGi based gateways for sensors and devices connection to the framework and one service provider OSGi framework hosting Euler as shown in Fig. 1.

[1] http://www.osgi.org/

[2] http://eulersharp.sourceforge.net/

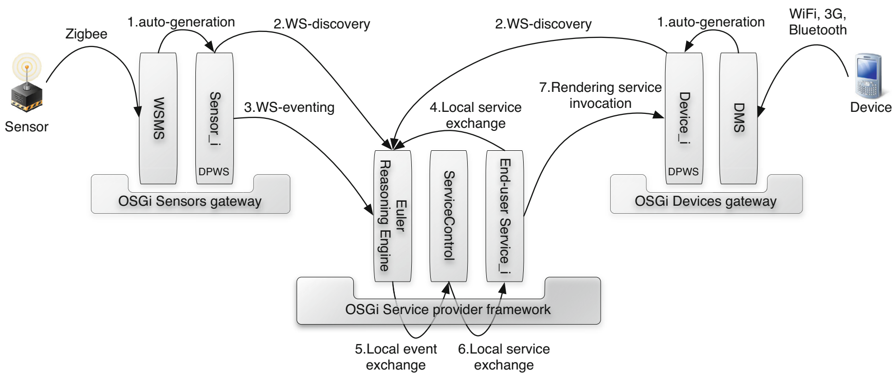

Fig. 1. Detailed architecture of our dynamic service oriented framework

3.1 The SOA Based Plug&Play Mechanism

To ensure the dynamic aspect of the framework, we have designed a Plug&Play mechanism allowing to present as a service any sensor or device discovered at runtime in the environment. The Wireless Sensor Management System (WSMS) bundle on the OSGi Sensors gateway was developed to manage the ZigBee connection with sensors deployed in the environment. It automatically generates a DPWS based bundle for each new sensor detected in the environment. The bundle generated contains a description of the sensor (type, ID, events, location, etc.) and its functionality. The type and ID information are deducted from the sensor packets received through ZigBee. Events' types are deduced from the sensor type. A simple configuration tool is also used to add some bindings to the sensor such as its location and the context it will be providing (for example, an ultrasound is configured to detect the presence near the washroom sink). This kind of information should not be integrated into the sensor so that it can be used for different contexts. A similar behavior is also realized on the OSGi Devices gateway where the Device Management System (DMS) communicate with devices through WiFi, 3G or Bluetooth and automatically generate DPWS based bundles describing these devices (type, id, location, rendering capability (audio, video, picture, text, light, etc.)) each time a new device is discovered. The auto-generation of bundles (1 in Fig. 1) consists of creating the `config` and `manifest` files specific for each entity, then packaging these files with the DPWS modules and the service classes. Service classes use the DPWS modules to manage the discovery of new entities by the service provider framework and to send events when sensors change their status or when an end-user service needs to be rendered on a specific device. WSMS and DMS generate these bundles and start them when new entities are discovered, then stop and remove them when entities disappear. Figure 2 shows the structure of the generated bundle of a Passive Infra-Red (PIR) sensor. Beside this mechanism of representing any entity in the environment as a service, the OSGi framework allows to integrate new end-user services at runtime without interruption of the framework functionality.

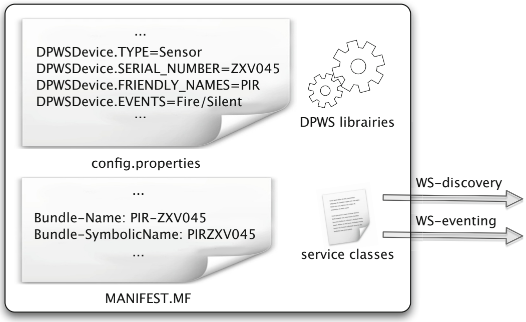

Fig. 2. Structure of a PIR generated bundle

DPWS is used as a standard communication protocol between the two OSGi gateways and the service provider framework. To ensure the adaptation to the environment changes and dynamism, once a DPWS based sensor or device bundle is created, it uses the WS-discovery protocol (2 in Fig. 1) to advertise itself and send its description to the framework.

3.2 Semantic Transcription of the Plug&Play Mechanism in the Reasoning Process

Even though the mechanical Plug&Play discussed above allows the integration and representation of sensors and devices as services, they are still not integrated in the reasoning process. Thus, it is not possible to use them in the selection of the end-user service and the interaction device. We introduce the notion of semantic plug&play to solve this problem.

To perform the selection process, we have integrated Euler semantic reasoning engine into the OSGi service provider framework and created a semantic representation of all entities in the environment (end-user services, sensors, devices, users, etc.) as well as their relations. This ontological representation is formalized in Notation 3 (N3), the syntax used by Euler.

In order to integrate new sensors and devices in the process, Euler detects new entities when it receives their WS-discovery events (2 in Fig. 1) and updates its representation of the environment with the semantic representation of these entities, extracted from their events. Context binding information obtained from the configuration tool are also integrated in the environment semantic representation. Moreover, to include new end-user services in the reasoning process, each end-user service integrated in the OSGi service provider framework uses the local service exchange to register with Euler reasoning engine (4 in Fig. 1), which adds its semantic description to the environment representation. In Fig. 3a we present the sensors abstraction model which is the skeleton for instantiating newly discovered PIR sensors in the environment such as the sensor having the N3 representation given in Fig. 3b.

```
### MODEL ###
aal:Sensor a rdfs:Class.
aal:PIR a rdfs:Class;
  rdfs:subClassOf aal:Sensor;
  rdfs:label """passive infrared"""@en.
aal:hasId a owl:DatatypeProperty;
  rdfs:domain aal:Sensor;
  rdfs:range xsd:string.
aal:hasEvent a owl:DatatypeProperty;
  rdfs:domain aal:Sensor;
  rdfs:range xsd:string.
```

(a) Sensors Model

```
### DATA ###
pirZXV045 a aal:PIR;
        aal:hasId """ZXV045""";
        aal:hasEvent """fire"""@en;
        aal:hasEvent """silent"""@en.
```

(b) PIR Sensor Instantiation

Fig. 3. Sensors representation in N3 syntax

Based on description logic rules, Euler is in charge of the context understanding and of taking decision, depending on the inferred context information, on the appropriate service to provide for the patient and the adequate device of interaction. DPWS-based sensors' bundles use the WS-eventing (3 in Fig. 1) to send sensor events to Euler reasoning engine when a sensor changes its status. Euler updates the sensor status and uses rules to infer the end-user's context. Other reasoning rules are written to select the appropriate service for the end user and the adequate device of interaction depending on the context information. Below are two example rules for the service and device selection:

$$\forall \; User\ u;\ Error\ e;\ Service\ s;\ Device\ d;\ Location\ l$$
$$(u\ perform\ e) \wedge (e\ needService\ s) \Rightarrow (u\ isInterestedIn\ s)$$
$$(u\ isLocatedIn\ l) \wedge (d\ usedIn\ l) \Rightarrow (u\ useDevice\ d)$$

Once Euler takes a decision on the service and device to use, the information is transmitted to the ServiceControl bundle (5 in Fig. 1). The ServiceControl bundle invokes the selected service while indicating the device to use (6 in Fig. 1). The selected service bundle uses the rendering service of the device bundle to provide its service on the chosen device (7 in Fig. 1).

4 Validation: Prototype and Results

We have developed a prototype of the semantic Plug&Play mechanism composed of the OSGi Sensors gateway running into a tiny fanless debian machine and the OSGi service provider framework running on an other machine. The OSGi service provider framework includes Euler reasoning engine with a configuration tool showing the detected sensors, their description, and the potential events received. There are numerous open source implementations of the OSGi specification such as Concierge, Knopflerfish, Equinox and Apache Felix. We chose the Apache Felix[3] framework which is lightweight, easy to use in standalone, made suitable for small device integration and implements the release 4 (R4) of the OSGi specification required for multi-containers communication.

[3] http://felix.apache.org/

The prototype was tested with low cost sensors, currently used in our project deployment, such as pressure sensors, accelerometers, ultrasound, PIR and RFID. These sensors are using ZigBee communication on a wireless sensor network based on Crossbow's IRIS mote platform. When one of these sensors is activated in the environment, it is detected by the sensors gateway. This is reflected in the GUI which displays the detected sensor and its specifications. It is then possible to configure the use of the sensor in the framework functionality from the GUI. Euler will use this configuration to infer users' context in the environment. In Fig. 4 we show the scenario of integrating an ultrasound sensor in the framework.

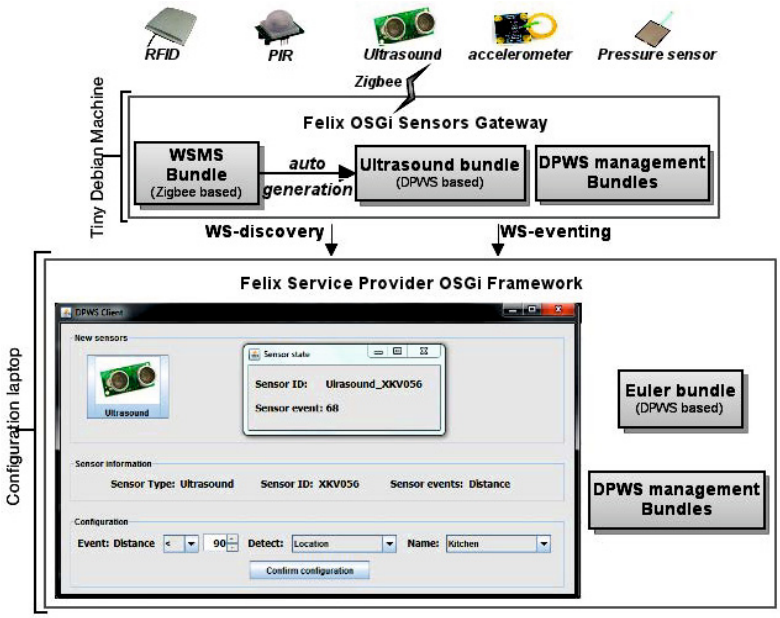

Fig. 4. Ultrasound sensor Plug&Play scenario

We have performed several tests on PIR, ultrasound and accelerometer sensors, that were not integrated in the prototype yet, to calculate the response time required to add the dynamic aspect. The experiment starts when the sensor is turned on in the environment and end when it is turned off. The time of semantic enrichment is calculated, however, the time for the GUI manipulation is not integrated as it differs depending on the user. Table 1 illustrates our results. In both the static and dynamic configurations, an average time of 0.224s is needed for starting the real sensor and for the ZigBee communication required to detect the sensor presence by the framework. In addition, for the dynamic configuration, we observed an additional average time of 0.373s needed to represent an ultrasound sensor as a service in the framework. This is the time required for generating and starting the bundle representing the ultrasound sensor on the gateway and for updating the N3 representation of the environment with the sensor information. The average time for stopping and removing the ultrasound sensor representation from the gateway was about 0.085s. These results represent the time difference between the static and dynamic configuration for starting and stopping sensors. The time difference looks acceptable when we know that it will allow to add a dynamic aspect to the framework.

Table 1. Sensor Plug&Play average time in seconds

	Sensor recognition time	**Sensor removing time**
Ultrasound	0.373	0.085
PIR	0.430	0.076
Accelerometer	0.437	0.061

Moreover, the time for context understanding, service selection and service rendering is the same in both the static and the dynamic configuration. Table 2 illustrates the results.

Table 2. Context understanding and service provision response time in seconds

	Context	**Selection**	**Rendering**
Response time	6.123	2.008	31.089

This prototype will be integrated in our current deployment in PeaceHaven nursing home in Singapore where our framework is used to provide services for aging residents with dementia. Our approach adds the ability to integrate new assistive services with their related sensors and interaction devices at runtime. As an example, to add the new assistive service "Wandering at night", we integrate its appropriate bundle in the framework then we attach a PIR sensor to the room ceiling and we put a pressure sensor under the resident mattress. The semantic Plug&Play mechanism allows to integrate the service and link its related sensors. Using the GUI, the PIR sensor is configured to detect the resident moving in the bedroom and the pressure sensor is configured to detect his presence on the bed. A set of first order logic rules are generated for the wandering at night service. During the night, if these rules are verified during a fixed period of time, then the resident needs an assistance to solve his wandering problem.

$$\forall \; \textit{Sensor s1; Sensor s2}$$
$$\textit{(s1 hasType PIR)} \wedge \textit{(s1 hasLocation bedroom)} \wedge \textit{(s1 hasStatus firing)}$$
$$\Rightarrow \textit{(resident perform movingInBedroom)}$$
$$\textit{(s2 hasType Pressure)} \wedge \textit{(s2 hasLocation bedroom)} \wedge \textit{(s2 hasStatus silent)}$$
$$\Rightarrow \textit{(resident perform notInTheBed)}$$
$$\textit{(resident perform movingInBedroom)} \wedge \textit{(resident perform notInTheBed)}$$
$$\Rightarrow \textit{(resident perform wanderingAtNight)}$$

5 Conclusion

The dynamic service oriented framework for AAL we have presented in this paper helps in the system adaptation to heterogeneous environments of deployment. The approach adopted contributes in easing the integration of new services, sensors and devices in the framework with a mechanism of semantic plug&play. A work similar to the sensors gateway will be realized for the devices gateway to reproduce the semantic Plug&Play aspect for devices. The prototype we have developed will be integrated in our current deployment in Singapore.

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A Macro and Micro Context Awareness Model for the Provision of Services in Smart Spaces

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Abstract. Context awareness and service delivery mechanisms help in dynamically adapting assistance offered to people with special needs (PwSN). However, implementing such systems in actual smart spaces is not trivial. The micro and macro context awareness model helps in defining layers on which contextual information are processed as close as possible from their sources (micro), without losing the benefits of information processing at a systemic level (macro). This paper describes the micro and macro context awareness model and its uses in the implementation of a service provision system for smart environments. Results coming from the evaluations of the micro/macro model and comparison with related works are also presented.

1 Introduction

The growing population of elders [14] with cognitive deficiencies and physical impairments, combined with the high costs and minimal supplies of caregiving resources, provide a compelling argument for a new vision of assistance at home [11]. Ubiquitous computing, context awareness and artificial intelligence techniques can transform human habitats into smart spaces able to provide assistance, contextual help and remediation by the environment. To assist these users in their daily living activities, dynamic and intelligent mechanisms are required to deploy assistive services on the different devices present in the smart environments, such as smart phones, tablets, desktop computers, laptops, embedded computers, etc. Such service provision mechanisms rely mainly on the use of contextual information from the environment and user profiles to accurately identify on which devices each service must be deployed.

Context awareness is needed in situations where software and hardware must collaborate in order to cope with complex data. A context aware system hosts software components that infer additional, synthetic context from the raw context provided by sensors and from other synthetic context. Context awareness enables such a system by assisting users in performing daily life activities or warns specialized personnel that human intervention is required. Software components can consume context, produce context for others to consume, or use context to decide upon an application domain-dependent course of action.

M. Donnelly et al. (Eds.): ICOST 2012, LNCS 7251, pp. 173–181, 2012.

In this paper, we present our work around the implementation of a context and user aware service provision system for smart environments (Section 3.1), based on the micro and macro context awareness model (Section 3). The micro context awareness revolves around the subjective perception and the understanding an environment entity has of its environment, while the macro context awareness is the global, emergent picture that components help build of entities in their environment [1]. This model helps in managing the complexity related to the quantity of contextual information and context sources, as well as providing headlines to build more versatile, dynamic and autonomous context aware systems. The micro/macro model drove the development of our service provision system, and helps with the organization and use of contextual information. Finally, this paper presents also an evaluation (Section 4) of the micro and macro context awareness model, through the service provision system implementation, and a comparison with two related works, Trumler et al. [12] and Ranganathan et al. [10].

2 Related Works

Over the two last decades, several works have been performed on context awareness, mostly about its utilization and modeling. Dey et al. [4] are among the first to have specified and developed a solution that implements a framework and a context model for ubiquitous computing.

In the CoWSAMI project, Athanasopoulos et al. [2] propose a context aware framework based on web services as interfaces to context sources and dynamically updateable relational views for storing, aggregating and interpreting context. Context rules are employed to provide mappings that specify how to populate context relations, with respect to the different context sources that become dynamically available.

In the SOCAM architecture, Gu et al. [6] propose a framework to support the rapid prototyping of context aware services. This framework is based on web ontologies to represent contextual information and use several protocols to discover context providers, bring information to the context interpreters and finally to the context aware services.

Several other works exists, proposing different approaches and technologies to support context awareness, e.g. the ESCAPE project [13] and Preuveneers [9]. On the other hand, some works in the area of service provision have developed context aware mechanisms to support service delivery in ubiquitous environments. Trumler et al. [12] are proposing a solution based on the social behavior of a cooperative group in the context of job assignments. The job assignments are based on the current context of the environment, which is held by the participant nodes, forwarded to a node responsible for the repartition of the services among the environment devices.

Some of these works propose answers to the difficulty encountered by today's smart environments (e.g. scalability, heterogeneity, privacy) by using a standardized definition of the contextual information through a semantic web language or addressing the complexity and heterogeneity of the smart environment through web service technology. These works provided a basis for the conception of our context awareness model and the implementation of our service provision system.

3 Context Awareness Model and Strategies

Different strategies exist to compute on the contextual information of a given system or environment. Such strategies are required to manage the complexity related to the quantity of data and information sources in complex smart spaces. For instance, it is possible to divide the context awareness of a given system in several sub-contexts called micro contexts [3], related to specific devices or closed locations. At a second level, it is possible to aggregate and combine the micro contexts with other sources of information to build a more global representation of the context in a given environment, the macro context or macro context awareness.

The macro context awareness is presented as something directly tied to a systemic model of the user and the conditions around this individual; the human is the center of attention. The system's main goal is to try to keep an up-to-date representation of a human and its environment. The human, given its central role in the world, becomes not only the main mutator of context, but is also the focus of the activity, making macro context awareness particularly well suited to applications that assist a given user in a smart environment.

On the other hand, the micro context awareness can be defined as the context awareness for devices that can be split up into three components: activity, environment and self. The activity describes the task the user/component is performing at the moment or more generally what his or her behavior is. The environment describes the status of the physical and social surroundings of the user/component. Finally, the self describes the intrinsic information about the user/component, e.g., preferences, capabilities, etc. Micro context awareness in smart environments relies on distributed computing to share and publish information between micro context components. Moreover, micro context components have to deal with ad hoc communications directly related to the ad hoc topologies of some environments. The hallmark constituents of controlled spaces, for example key nodes, can be used in micro context but cannot be depended upon by individual components. Micro context awareness is not only awareness of a single component, sometimes named raw context, but rather a model of context awareness that focuses on information available to the acting components and that maintains no dependence on system-wide knowledge or tools.

In comparison to the works presented in the previous section, we believe that a context aware system should use both perspectives to build software that better adapt to different situations and are less complex to deploy and manage. We will now present how we build the service provision system using both layers.

3.1 The Service Provision System

An intelligent service provision system allows dynamic, fast and adapted service deployment toward the users in the environments, based on the context of the environment and takes into account different constraints such as the users' capabilities and their preferences. We implemented a middleware for smart homes/apartments dedicated to the self-management of the software deployed in these environments [5]. Rallying several technologies e.g. Web Services, OSGi, OWL ontologies and fuzzy logic, this middleware uses the contextual information of the environments to find the devices that are the most adapted to the service needs, user capabilities and preferences, device resources and environment topology. The main goal of the proposed service provision system is to support the deployment of the assistive services into the smart environments for other smart systems like activity recognition or error and failure recognition systems to use. These systems use the service provision functionalities by supplying information related to the service to deliver, e.g. Which users are targeted?, Which assistive services?, What are the service needs?, Is there a specific zone of the environment that is targeted by the assistance request?

The service provision mechanisms use four main context elements: user profiles, environment device profiles, topology of the environment and software profiles. Each service that needs to be deployed in the environment has hardware, software or contextual needs. On one hand, assistive applications like a meal preparer assistant or a context aware calendar and organizer, can target particular users in the environments and can require specific peripheral devices. On the other hand, users have physical capabilities and preferences (preferences toward specific interaction peripherals such as keyboard, touch screen, mouse, etc.) about the environment devices; the devices also have profiles with capabilities e.g. their resources, connected peripheral devices, etc. All these components are present in the smart environments at different (or not) locations and are related to contextual zones e.g. the kitchen, the bathroom, the living room, etc. Finally, the user profiles describe a user's physical capabilities, e.g. their visual acuity, walking speed or their hand workspace, their interaction preferences and their location in the environment.

In our work, we used the micro and macro context model to divide into layers the reasoning on the contextual information related to the service delivery. We therefore divided the system into two kinds of components: Device nodes and Coordinator nodes. Device nodes collect the information related to their hardware, their location in the environment and their connected interaction peripherals. This information is processed, along with an abstracted representation of the service to deploy (provided by the coordinator node), within a Fuzzy Logic controller [7]. This controller determines if each device has the resources to support the services to deliver and at which performance/quality the device can support the service in question (with a performance score between 0 and 100). Such information is shared with the other components of the environment along with an abstracted representation of the device. The Device nodes have subjective views of their surrounding and a partial view of the environment through the data forwarded by the coordinator nodes or the other device nodes.

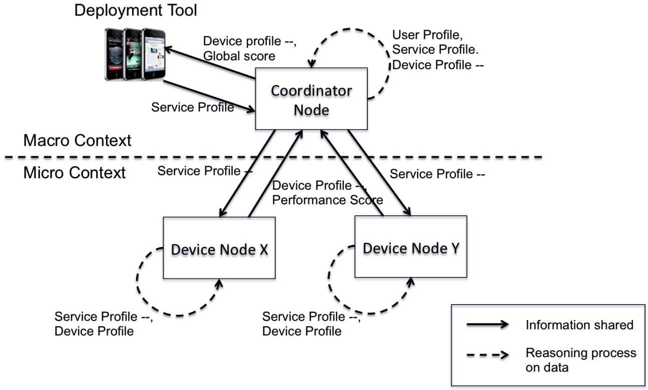

Fig. 1. Utilisation of the contextual information in the service provision system

The coordinator nodes have the responsibility to receive service provision requests and manage the reasoning process about which devices in the environment are the most appropriate to support the services. Depending on the service needs, the coordinator nodes take into consideration the profile of the users to determine which device is best adapted to user capabilities and interaction preferences, and the topology of the environment, i.e. in which environment zones users and components (devices and peripherals) are in. This information is computed with the abstracted representation of the micro context and the performance score computed by the device node. To do so, the coordinator node uses an OWL ontology and a second Fuzzy Logic controller to make the final decision about where each service must be deployed. The contextual information processed by the Coordinator node is directly related to the macro context awareness level. The users are the central focus point of the reasoning process in the Coordinator node and these nodes have a systemic and consistent view of the environment context, partially provided by the abstracted micro contexts. Figure 1 presents the use and exchange of the contextual information between the Coordinator node and a Device node, respectively related to the macro and micro context levels.

One direct benefit of dividing the service provision system in two context awareness layers is the reduction, on each layer, of the quantity of data managed. Moreover, dividing the contextual information in different layers reduces the strong coupling that can exist between information, reducing the complexity of updating information across layers. For instance, in the service provision system, the Device nodes know their location in the environment, but don't know directly in which logical zone they are, as this depends on a more global view of the environment.

Another benefit of the micro and macro context awareness layers is to prevent the divulgence of sensitive information between software components. In the case of the service provision system, user profiles are kept in the Coordinator node, avoiding publication of private information such as user interaction capabilities and preferences. Another benefit is the non-divulgence of the service profile, with each Device node receiving an abstracted representation of the services to deploy until they are finally selected for the deliveries, keeping private the real nature of the services and the provided assistance. Finally, distributing the processing of the contextual information among layers and nodes has an important impact on the performance of the system. Using macro and micro context layers allows leveraging of the processing capacities of the different devices in the environment and reduces the computing time of the macro context layer (less information to process). Some results on the distribution of the reasoning processes for the service provision system are presented in Section 4.

4 Evaluation and Results

Throughout the technical evaluation of the service provision system, we evaluated the macro and micro context awareness approach applied to service delivery in a smart apartment. The evaluation was conducted in a real smart apartment, composed of 8 device nodes, 1 coordinator node, 25 and more interaction peripherals and over 50 context sources e.g., sensors, localisation system. We use different kinds of user archetypes in five assistance scenarios based on the validation used by Gouin-Vallerand et al. [5].

Firstly, we compared our approach with the similar work of Trumler et al. [12], which can be categorized as a micro context aware system. As Trumler et al. did, we evaluate our system by counting the number of messages exchanged for a given service delivery job. The number of messages exchanged in a distributed system for a specific job, can be a good way to compare the intrinsic complexity of systems [8], when the types of data and the amount of information are fixed. In the case of the macro and micro context aware service provision system, the number of messages exchanged between the nodes correspond to $Messages = (a \times d) + d + 1$ where d is the number of Device node and a is the number of services to deliver. Therefore, for five services to deploy in an environment with ten devices, the number of messages is 61 messages. For the same configuration, the solution of Trumler et al. in a similar configuration used 35 messages. However, if the nature of the information is the same (XML stream) in both works, the amount of information used by each system is different. Compared to Trumler et al.'s work, our service provision solution uses a more complete description of the services to deliver and involve the topology and the user profile in the reasoning process. Moreover, the Trumler et al.'s work groups several informations together in the same message, which reduce the amount of messages but not necessarily the complexity behind their reasoning process.

On the other hand, Ranganathan et al. [10] proposes a centralized solution involving the processing of the information based on a macro context awareness perspective. They measured the performance of their work based on computing, where their system took an average processing time of 0.93 second on a Pentium M 1.7 GHz system, for a scenario with two services deployed among five devices.

Table 1. Processing times of the service provision system's components

Component	Average computing time (sec)
Coordinator Node	0.12
All Device Nodes	0.06
One Device Node	0.01
All Web service calls	0.28
One Web service call	0.011

In comparison, our micro and macro solution takes 0.55 second for a similar scenario with eight devices, plus the computing related to the user profiles and where the system was composed of devices ranging from Intel Core 2 Duo 2.4 GHz to Tablets processors. This computing time included the Web service calls related to the 23 messages/requests exchanged during the service provision.

Of course, comparing computing times from systems with different hardware and setups is difficult. To push the comparison further, we measured the average computing times related for the system's software components and the communications (Table 1). By using the Passmark benchmark scores of the processors, 434 for the Pentium M and 1508 for the Core 2 Duo [1], which give a ratio of 3.47 in favor of the Core 2 Duo. Using this ratio with the average computing times of the Coordinator and Device node ($0.12 + 0.06$ seconds), the approximation (with an unknown error margin) of the computing time of the proposed solution on a Pentium M would be of 0.62 seconds (0.18×3.47). One conclusion from this exercise is that the web service calls represent a bottleneck for the performance of our system. In the case of the service provision, the distributed nature of the system cannot be avoided and is an intrinsic part of the solution. However, by adding to approximated computing time the web service calls (assuming that there is only small variations between the two hardware), the performance of the proposed solution is around the Ranganathan et al.'s result, with more data processed and the benefit of the micro context awareness in the favor of our work.

Finally, these results show that the proposed service provision system implemented using a micro/macro context awareness approach gave results that are at least equivalent to the other related works. As the complexity and the amount of data processed by our solution are higher, we had to use state of the art technologies (e.g. web services, OSGi framework, OWL ontologies, Fuzzy Logic controllers) to help us in implementing our approach, which would have been more difficult five years ago without them.

5 Conclusion

Today's smart environments are synonymous to context awareness, component dynamism and adapted services to assist the users in their daily living activities. If context awareness brings tools to increase the system adaptation to the

[1] Passmark benchmark : www.cpubenchmark.net

surrounding environment, its implementation is not trivial. The micro and macro context awareness approaches help categorize to which kind of context each system component should be related, depending on the role of the components and the type of processed information. In this paper, we present our work around the implementation of a service provision system for smart spaces, based on a model where the processing of the contextual information is divided between a macro and a micro context awareness layer. This approach allows us to manage the complexity related to the contextual information, by processing data as close as possible to their context sources, with the Device Nodes, without losing the benefits of information processing at a systemic level, with the Coordinator nodes. We are currently working on the formalization of a model of the macro and micro context awareness approach and we are planning to implement it in large-scale systems for controlled smart spaces (e.g. smart homes) and open smart spaces (e.g. smart cities). The formalization of the model will help in implementing the functionalities to support both context layers, in environments where the quality of service can vary greatly.

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ACARP: Auto Correct Activity Recognition Rules Using Process Analysis Toolkit (PAT)

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Abstract. Activity recognition within ambient environments is a highly non-trivial process. Such procedures can be managed using rule based systems in monitoring human behavior. However, designing and verification of such systems is laborious and time-consuming. We present a rule verification system that uses model checking techniques to ensure rule validity. This system also performs correction of erroneous rules automatically, therefore reducing reliance on manual rule checking, verification and correction.

Keywords: Model Checking, Rules Verification, Rules Auto-correction.

1 Introduction

The challenges facing Ambient Assisted Living systems are in providing activity recognition of assisted people and also rendering adequate assistive services. Rule based activity recognition is able to provide dependable assistance services based on sensors integrated into the living ambient environment [2,8]. The rules within the system define the activities to be recognized. However, the correctness and reliability of the rule base remain a non-trivial problem. Incorrect or vague rules could impair the system's capability in determining activities, which could then result in a lack of, or inappropriate service to be offered. Unreliable rules would also provide a misleading reflection of the actual situation, which is unacceptable in mission-critical or urgent scenarios. The task in correcting relatively large rule repositories is considerably laborious. Therefore there is a need to construct a system that is able to verify and ensure the specificity of rules, and to also automatically correct the erroneous rules.

We deploy a rule based activity recognition system, known as AMUPADH [3] in PeaceHaven nursing home[1]. We illustrate the challenges found by our rule based activity recognition systems:

[1] http://www.salvationarmy.org/smm/www_smm_singapore.nsf/vw-sublinks/01F5FF03C34EED77802571260011BE69

M. Donnelly et al. (Eds.): ICOST 2012, LNCS 7251, pp. 182–189, 2012.

- The AMUPADH system incorporates a reasoning engine that performs activity recognition based on rules that are pre-determined by domain experts, which in this case pertains to nurses and caregivers stationed at PeaceHaven. These rules assist the system in monitoring residents' activities and provide the appropriate reminder prompt to residents through reasoning.
- We observe that although monitored residents perform Activities of Daily Living that is consistent with prior information provided by nurses, there are still occasions where information provided by nurses is insufficient to construct a system that can recognize all the resident's activities. Hence, it is possible that the system could still provide erroneous prompts.
- We determine that these issues are a result of the rules' inability to infer and recognize all activities based only on first order descriptive logic. Rules are also created with logic loopholes due to unawareness of actual scenarios. We are also unable to fully capture factors involved in the changing ambient environment within our rules. Therefore such logic flaws could only be exposed during actual deployments and due to limited granularity and coverage of our sensors, in addition to uncertainties within the ambient environment, the manually defined rules did not perform up to expectations.
- The resulting system thus becomes very difficult to debug because of the relatively large number of rules and various scenarios that have to be tested in actual deployments to ensure the system is working.

We propose ACARP, an automatic approach which is based on exhaustive manipulation of all possible scenarios to tackle this rule verification problem.

- We perform formal verification of critical system properties through the usage of model checking techniques and PAT [10] model checker to verify proposed properties as defined in Section 3.4. Automatic correction strategies of the detected errors are provided in the tool to ease the management of the rules. Through the usage of ACARP, we discovered unexpected bugs and system design flaws within our AMUPADH system.
- CSP# [9] is an expressive modeling language which is adopted in ACARP as formalism to model resident behaviors since it combines high-level compositional operators obtained within CSP with low-level programming constructs. Communications within the system are modeled using synchronous channel communications.
- Patients' behaviors within our model are detected through ambient sensors via event synchronization and activity recognition is conducted by feeding sensor inputs into the rule engine, which would then generate appropriate responses to be forwarded as reminder prompts.
- The modeling of our context-aware system is based on the common architecture of current context-aware systems, such that other context-aware systems can also be modeled in a similar fashion.

2 Related Works

In rules verification, anomalies are identified and classified into different categories. Various algorithms are proposed to detect anomalies in order to build robust systems. Ligeza and Nalepa [6] reported state-of-the-art rule representation and types of inferences. Taxonomies of rule anomalies are proposed regarding redundancy, consistency, completeness and determinism. However, their rules are simple compared to context-aware rules that are used in our system. In addition, there was no discussion regarding the detection and resolution of anomalies too.

Drools verifier [1] from JBOSS community also performs rules verification. This tool searches for anomalies such as redundancy and subsumption but their approach is based on merely syntax analyzing and it lacks the ability in discovering high level semantic errors such as conflicting rules.

Preece et al. [7] surveyed the verification of rule based systems focusing on detecting anomalies. They described four types of anomalies regarding redundancy, ambivalence, circularity and deficiency. Five rule verification tools are compared based on their capability of detecting the four anomalies. They provide insights on underlying principles of rule verification and state of the art in building a tool for carrying the task. However, their definitions for anomalies and the surveyed algorithms are not directly applicable to our system. Firstly, their methods are based on the syntax and semantic logics between rules instead of the rule effects on the system behavior. Secondly, the algorithms are mostly designed for goal driven rules, such that the conditions and consequents of a rule have strong causal connections and consequences are true only when all conditions of a rule are satisfied. This might not necessarily be true in our ACARP system.

Researchers in [5] used Ambient Calculus to model a location sensitive smart guiding system in a hospital. The mobility issue is well modeled and reasoned in their work using modelling methods, but without adopting a rule-based approach. Our work is able to adopt hierarchical modeling languages which is also supported by model checkers like PAT for automatic verification.

Therefore, new methods for analyzing rules in our ACARP system are needed in consideration of our context-aware rules.

3 ACARP Rule Checking System

Rules and their respective rule engines are considered to be an important part of human behavior and activity monitoring systems. Rules can be complicated and crucial for real-time and mission critical applications, especially for healthcare purposes. However, it is difficult to manually discover and correct errors within relatively large number of rules. As evidenced in the modeling and verification of the AMUPADH system, rules can be checked using model checking techniques, and counter examples reported by model checkers can be used to identify possible errors in the rules. In the following subsections, we explain how ACARP can parse Drools rules into CSP# and also auto-correct rules. Special properties of rules are discussed and defined within this work.

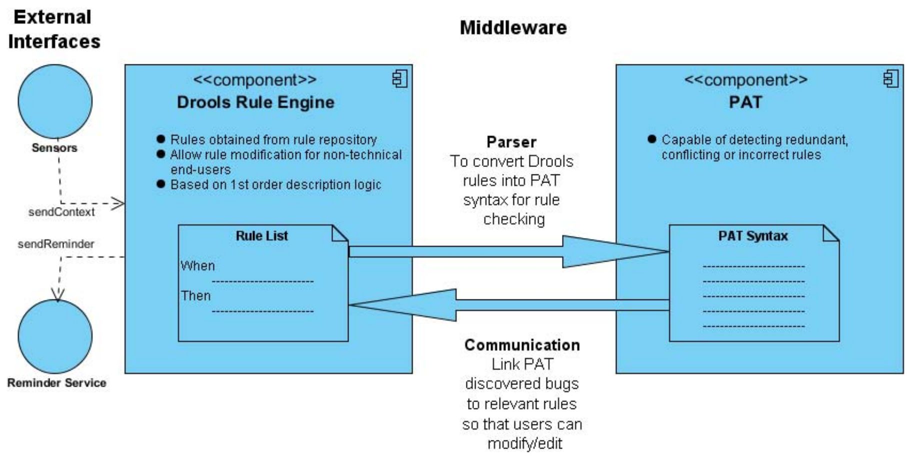

Fig. 1. Auto Correction System Component Diagram

3.1 Drools Reasoning Engine

The Drools [4] reasoning engine contains rules that can be written using first order descriptive logic. Rules are able to handle scenarios with multiple conditions(IFs) and consequences(THENs). Context-aware reasoning engine [11] is proposed and implemented within our AMUPADH system. However, complicated scenarios with overlapping activities cause logic flaws and some rules are unnecessarily activated. When certain rules are changed, other rules dependent on these modified rules can become redundant. Additional rules that are inserted to complement present rules can also further complicate the system.

We tried overcoming these problems by appropriately classifying the rulesets into different groups of rules. Any modifications made to a group of rules would affect only rules within the particular group. However, this is not a perfect solution as there would still be situations where rule conflicts would occur between different rule groups which are used to monitor the entire smart home. Therefore the model checker PAT would be used to help resolve this problem by performing rule checking and verification.

3.2 System Workflow

As shown in Figure 1, the system is designed to incorporate a parser that takes Drools rules and Java classes as input, so that the system can automatically produce a model in PAT. PAT subsequently checks the newly-created rule model against the properties defined in Section 3.4. If some properties are satisfied, a counterexample will be reported. PAT then analyzes and traces the report to locate the erroneous rules and autocorrect them according to predefined logic, or the system can also alert users to perform manual correction.

3.3 Auto-Modeling of Drools rules

We use Drools because it is a popular rules platform widely adopted in research fields and industries. Drools Expert[2] is an open source rule engine maintained by JBOSS community. It is broadly applied in recommendation, financial security and other business systems. The language syntax of specifying Drools rules is based on first order descriptive logic and external methods and classes written in Java can easily be used in Drools. PAT supports both of these features such that first order logic can be directly mapped to its form in CSP#, and Java classes can be parsed into C# external library, which can be called in CSP# models. Therefore, we parse Drools rule syntax into CSP# in PAT.

For usage of temporal rules with our approach, users are required to use the Real-Time System (RTS) module within PAT. Our approach in this paper assumes sensor inputs are true and without uncertainty. The full syntax of Drools is quite expressive and the general pattern is shown in the example below. Interested readers are encouraged to read [4] and [11] for details.

```
rule "Person lies on BedA, Wrong Bed"
    when   s1: Sensor(id == "RFID", name != "PersonA")
           Sensor(id == "BedA", state == "LYING")
           msg: MessageInterface()
    then   msg.send("Error: " + s1.getName() + " is lying on wrong bed.");
end
```

The above rule example obtained from the AMUPADH system clearly defines the conditions and consequences describing the situation of a person lying on the wrong bed. The bed has a RFID reader and pressure sensors installed. When a person other than "PersonA" uses the bed and registers a pressure status of $LYING$, an alert message is sent . Note that the symbol "s1" gives a name to an object or field that can be later quoted in the scope of this rule and "Sensor" can be viewed as a field or a point for external method call or object reference.

Parsing DROOLS rule to CSP#. After identifying the general pattern of Drools rules, the mapping of rules are defined in this section.The rule engine consists of the main rule file and the Java classes that specify global variables and external methods. We manage the parsing process as listed below:

Step 1: Extract Shared Information For the purpose of easy management, the shared information is declared and kept in Java classes instead of rule files. This information includes the global variables and constants.

Step 2: Mapping Rules into CSP# The parser processes the rules one at a time and splits the rule into three parts, namely the rule name, conditions and consequences by reading the keywords *rule*, *when* and *then* respectively. We then map the Drools rule into CSP# by mapping rule names into rule associated comments, the conditions to ifa expressions, and the consequences into ifa statements, so as to point to the next rule.

[2] Drools Expert: http://www.jboss.org/drools/drools-expert.html

The two-step parsing tool automates the process of modeling rules and reduces the time required for verifying rulesets. When operators like && are used to differentiate rule priorities, human intervention might be required in rewriting certain Java classes into C#. However, experience shows that this effort is minimal, since Java classes are seldom changed during system development.

Users who understand the context and usage of the rules are most suited for conducting this process as the generated model's performance is dependent on the user's expertise in accurately translating rules and inclusion of additional embedded semantics from Java classes into the PAT model. Our approach is currently unable to treat rules with priorities and rule chaining, but these are extensible work in progress. The choice of using a different rule engine is also possible, but it would need to adhere to PAT's input requirements.

3.4 Auto-Detection and Auto-correction of Rules Anomalies

We model anomalies as properties within PAT. Based on results and feedback obtained from the AMUPADH system deployed at PeaceHaven nursing home, we identify the following critical properties:

- *Property 1: Non-reachable rules*
  Non-reachable rules are trivial as some rules' conditions are never satisfied during ruleset execution. These rules can be unintentionally introduced by rule developers. Although the system's correctness is unaffected, they add complexity to the model and slow down the rules evaluation process. *Detection* of these rules is done by checking if every rule is reachable during the exhaustive search of system state space. *Correction* by automatically removing such unnecessary rules is offered by the ACARP system.
- *Property 2: Redundant rules*
  Redundant rules are occurrences of multiple firing rules that produce identical system results. We define two kinds of redundant rules, *duplicated rules* and *overlapping rules*. The former refer to rules that have same conditions and consequences, whereas the latter applies to rules with same conditions but different consequences. The *detection* of these rules can be done by checking if the two rules in question are overlapping and always fire together. We perform *correction* on these rules, by removing one of the rules if both sets of conditions and consequences are identical. If the consequences are different and not conflicting, we merge them into a single rule and classify the remaining rules as conflicting rules.
- *Property 3: Logically Conflicting Rules*
  Logically conflicting rules are rules that satisfy all conditions at a particular state, but the consequences are not logically sound and thus are conflicting. This property cannot be easily detected in routine system tests and the possibility in finding this property using additional model checking techniques is still dependent on the designers' experience in finding such rules. We *detect* this error by checking if possible pairs of conflicting rules can happen at the same time and analyze the rule traces, so as to point out the conflicting pair of rules for manual *correction*.

Table 1. Results of Experiments

Scenario	# Rules	# Non-reachable	# Redundant/ #Duplicated	# Conflicted
Bedroom	17	2	8/3	2
Shower Room	22	5	16/2	-
Avg. Time(s)	-	2.05	3.05	-

4 Experiments and Discussion

We tested our implementation on two rulesets, which are rules used for two respective areas, namely the bedroom and shower room. As shown in Table 1, the two rulesets contain rules that are paired and tested for anomalies of non-reachability, redundancy and logic conflicts. The advantage of using PAT over other model checkers is that it provides feedback consisting of counterexamples or traces of actions if any anomaly is detected, which is very useful for analysis of our system. The traces can point out names of erroneous rules and their respective violated properties. The activity sequence that leads to the property violation will also be listed out.

From the experiments, we found cases of the following anomalies. In the bedroom scenario, our system detected a rule that was non-reachable even after an exhaustive simulation of all possible situations. We realized that it was a rule defined to recognize an activity of opening a cupboard. However, in that particular state of the system at the time of detection, there was no sensor deployed to detect such an activity. We subsequently confirmed that rule developers forgot to remove this rule from the repository even after the use case of recognizing cupboard usage has been previously abandoned. During the test for redundancy, ACARP discovered five duplicated rules which were accidentally added into the rule repository for testing and were not removed due to negligence.

Multiple pairs of logically conflicting rules were discovered within the rulesets used for our PeaceHaven deployment of the AMUPADH system. We also observed multiple reminders that were simultaneously prompted to the same user and we tried replicating such conflicting scenarios using the model checker PAT. The verification result with regards to the reachability of this defined scenario turns out to be valid within our model, thus providing us with a trace that denotes the monitored user have been showering for a long period of time, yet continues to ignore the reminder that prompts him to use the shower foam. This was the reason that led to the triggering of two contradictory reminders that request a user to perform activities in two different locations at the same time, which is physically impossible. We were able to trace this situation using our ACARP system.

Discussion. From the experiments, we discovered the stated anomalies as described by our defined properties. They could be caused by changes made to the scenarios or rules. It is impractical to manually examine and verify the validity of relatively large rulesets. Moreover, some existing rule verification techniques can only perform simple syntax checking which fail to detect logical conflicts. The other techniques and methodologies also could not be used in our system due to the high level language features used within modern rule engines, in addition to the lack of general tools and support. Hence, our approach is required in order to provide and perform features as stated within this paper and in addition, also effectively detect the defined anomalies and be able to perform customized verification for other testing purposes.

5 Conclusion

In this work, we presented a system that is able to use model checking techniques and the model checker PAT in performing rule verification of activity recognition rules within a smart home environment. We used Drools engine and tested our rules within a deployment scenario at a local nursing home. In order to ensure validity of the rules, we created a model of the rules and checked for non-reachability, redundancy and logically conflicting properties of the rules. These three important properties allow us to evaluate the rules and also assist in automatic rule correction, therefore reducing reliance on human intervention and the time needed for verifying the entire ruleset.

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An Extensible Situation-Aware Caring System for Real-World Smart Wards

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Abstract. Context-aware caring system is capable of effectively improving quality of health care in hospitals. Most of current context-aware health care systems adopt only simple context information, which only provide limited supports to caregivers. In this paper, we present the design and evaluation of a new situation-aware caring system for smart wards, which combines multiple contexts and infer patients' "situations". This system is built and evaluated in a real-world hospital. We also report lessons learned, preliminary results of empirical deployment, and questionnaire surveys of caregivers.

Keywords: Smart Ward, Context-awareness, Situation-awareness.

1 Introduction

It is widely recognized that large proportion of publics begins to experience debilitating conditions such as chronic illness or disabilities. Developers of health care applications have long noticed this trend. Hence, many research projects have evolved to enable a health caring space, e.g. a smart ward, capable of observing surrounding context and thereafter making adequate decisions. Such capabilities are currently defined as being context-aware [1]. Most projects and prototypes percept the contexts in order to infer user intention, and do whatever necessary to help the user accomplish his or her tasks. As for the term "context", we use the definition proposed by Dey et al. [1], where a "context" is any information that can be used to characterize the situation of an entity which can be a person, place, or object. On the other hand, the term "situation" is the context that is derived from one or more contexts based on situation inference mechanisms (will be discussed in Section 3).

Bricon-Souf et al. reported that most of these context-aware health caring systems use only simple contexts (e.g. timing, human or artifact locations and

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states, user identification, and bio-information) which are too naive to infer human intentions [3]. Further, the contexts used are not well-organized, lacking context information leads to poor service quality. We therefore propose a new "situation-aware" caring system for smart wards where a "situation" refers to a new type of context extracted by knowledge-involved inference engines, given basic context information. Besides, the proposed system is constructed bases on ambient wireless sensor network for ultimate context perceiver, which differs from previous projects using wearable sensors (like RFID) or privacy-intrusive sensors (like cameras) to extract contexts. Further, the design of the proposed system is based on a highly extensible architecture called Message-Oriented Middleware (MOM). Hence, it is easy for application developers to deploy new components with minimal modifications to the overall system, which is one of the most critical requirements in real-world smart wards. As a result, these applications built based on the proposed system better satisfy the real demands from the medical professionals and caregivers.

2 Related Work

Situation awareness and extensibility are both important qualities of smart ward caring systems in a real-world environment. Although many systems or applications for smart wards have been proposed so far, few of them are both situation aware and highly extensible. Among them, Bardram et al. and Kjeldskov et al. [4,5] have carried out projects that assist medical works in a real-world hospital. These works use context-aware artifacts such as beds and pill containers. However, the information provided by the systems is limited to location-related contexts. Besides, a context-aware health care system for automating hospital message delivery is proposed by Munoz et al. [6], where location, time, role reliance, and artifact states are used as possible contextual elements for message delivery. Mitchell et al. [7] also proposed another prototype aiming for facilitating instant mobile communication between medical staff and patients by identifying roles by wearable active badges. The above-mentioned systems integrate context information in order to provide services. However, none of these works analyzes contexts in a systematic way, thus providing only limited information to caregivers. In this work we propose an extensible situation-aware system for a real-world hospital environment in which the software and hardware modules can be replaced on-the-fly and makes use of context in a more sophisticated way by deriving situations from contexts.

3 System Architecture

The overall architecture of the proposed system is depicted in Fig. 1a and Fig. 1b. Figure 1a is the horizontal view of the system where all modules interact based on MOM, which is an event-based mechanism that enables asynchronous communication and loosely-coupled integration. MOM creates a virtual "software bus" for integrating heterogeneous message publishers and subscribers, namely, the

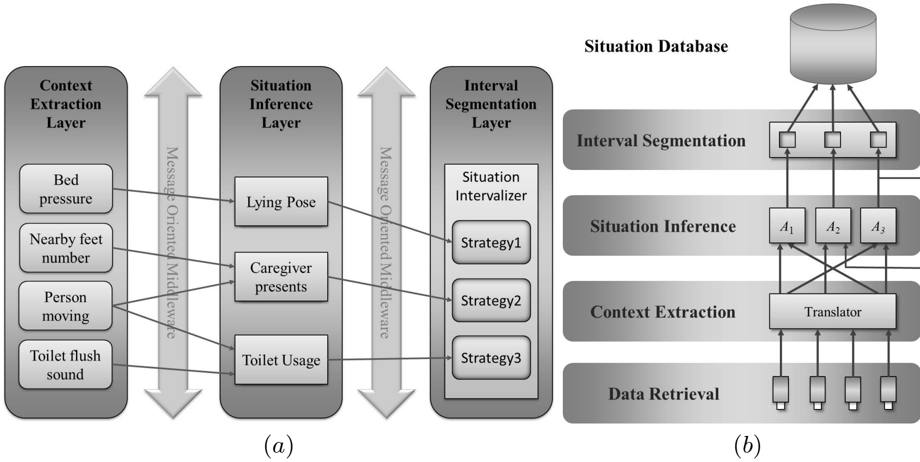

Fig. 1. The architecture the proposed system (a) Horizontal view; (b) Vertical view

"nodes". The logical pathways between nodes are called "topics". Based on this architecture, the system provides services by chaining nodes and topics together. Hohpe and Woolf [2] point out that when compared with other paradigms, messaging is considered more immediate than file transfer, better encapsulated than shared database, and more extensible than RPC-based invocation. Figure 1b provides a vertical view of the system which shows the data flow from bottom to the top, and then are persisted to a situation database. The persisted results can be categorized into two types: situation records and situation interval records. The former describes an environment state at a specific time whereas the situation interval records refer to a set of continuous environment events. In fact, the situation interval record is derived from situation records by Interval Segmentation. The detailed functionalities of each layer are explained below.

Data retrieval: A sensor network is deployed in the ward. A possible output of this layer looks like $[P_3, 0]$, which indicates a 0 read value for pressure sensor P_3 deployed on the mattress. In order not to interfere with patients' daily activities, the wearable sensors and privacy-intrusive sensors such as cameras should be avoided [8].

Context extraction: This layer consists of a set of components that translate the raw data into contexts. The translation logic is usually application specific. For example, one can determine a threshold and accumulate the values above the threshold. It is worthy to point out that translating continuous data (e.g. sound wave amplitude data) to a context such as "speaking". Sophisticate mechanisms based on pattern recognition are often used in this layer. A possible output of this layer can be $["upperbed", "off"]$, which indicates that the pressure sensor deployed on the upper bed is not pressed. The translated contexts are subsequently sent to a specific topic in the MOM.

Situation inference: Components belonging to this layer perform situation inference (usually by using machine learning techniques) from contexts. Specifically, this layer consists of several independently running inference components, each of them subscribes to a set of contexts or situation topics in MOM and is responsible for identifying a specific situation based on these data. For example, the situation [$"lyingpose", "leavebed"$] can be inferred after inspecting all pressure-related contexts (currently we mainly use HMM model, with input being a vector of 15 real number input from pressure straps, for recognizing all 11 possible pose states [9]). Note that some situations can be obtained by cascaded inferences. For example, if a situation [$"caregiverpresent", "false"$] is perceived, then [$"lyingpose", "leavebedalone"$] may also be inferred. Also note that since our system is designed based on MOM, one can easily extend the situation recognition capability of the system by introducing new inference components (See Fig. 1a).

Interval segmentation: Sometimes it is more informative to show the exact period of a specific situation to caregivers. This layer therefore exists for aggregating consecutive contexts or situations into one interval record. For example, [$"lyingpose", "01/10, 12:03:54", "01/10, 12:15:39"$] is a situation interval record. Since the segmentation process is usually application specific, we design this layer by applying the Strategy pattern [11] so that each situation interval type is handled by a specific segmentation strategy. This design improves the extensibility of the system. As part of output, the situation records, generated in situation inference layer, can be retrieved from the MOM. Meanwhile, the situation interval records can also be retrieved after persisted to the database.

4 Applications

In this section, we briefly introduce two real-world applications which has been built based on the proposed system. New situation-aware health care applications can be easily built based on the proposed system.

4.1 Situation Alerting

The first application called situation alerting is capable of notifying pre-configured alert event to caregivers, e.g. falling, so that caregivers can give help as soon as possible. Products [10] are there and proved to successfully detect target conditions, but they can not detect sophisticate situations such as "patient goes to bathroom alone and stays over 5 minutes" (possibly indicating an occurring accident). The application subscribes alert events from the MOM by specifying that only those situation records whose type matches the situation that is interested. Then, the monitored event list is adjusted accordingly. The current prototype is able to monitor the following situations: *Patient enters the bathroom (alone)*, *Patient leaves bed (alone)*, and *No caregiver presents.*

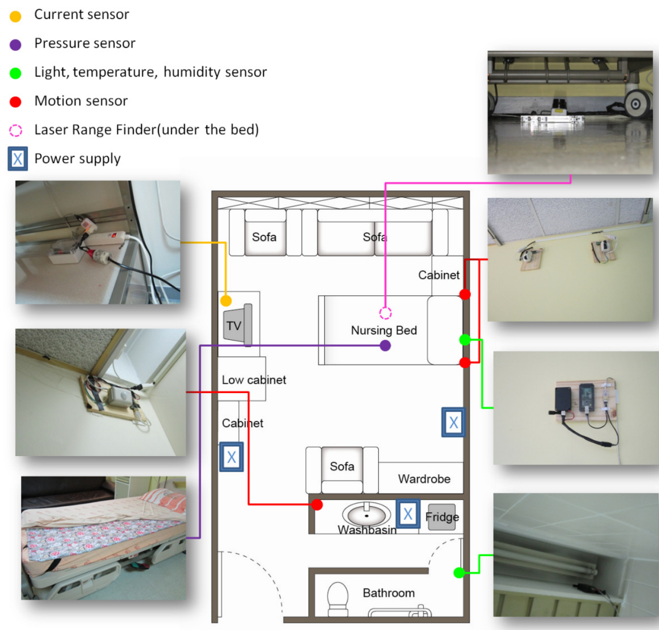

Fig. 2. The configuration of the real-world smart ward in NTUH

4.2 Situation Reporting

The second application is a reporting system that provides integrated view of patient situation by aggregating observed data and generating a graphical summary report. Traditional electrical medical reports offer only bio-related measurement information such as heartbeat rate or blood pressure. According to our preliminary interview to medical professionals, we notice that they require more informative and high-level information to assist them in making decisions. For example, clinicians may want to check if the total time leaving bed of a patient is at an increasing trend every day, and gives different prescription accordingly. We therefore design a Situation Reporting application that aims to fulfill this requirement. The summary report is mainly chart-oriented, and users can switch to different views based on their requirement.

5 Evaluation

In this section, we briefly introduce the deployment of our prototype to a smart ward of a real-world hospital, which evaluates the feasibility of the proposed system. Then, we present the results of preliminary surveys of satisfaction assessments as well as lessons learned when constructing this prototype.

5.1 System Implementation and Deployment

We have realized the proposed system and deployed it in the Rm. 9A03 of National Taiwan University Hospital (NTUH). To better assess the requirement of medical professionals and caregivers, we conducted several interviews with clinicians, nurses, and psychiatrists, for eliciting target situations that medical professionals emphasize most when evaluating the recovering progress. Based on the results, we chose to recognize the following situations: (1) Lying pose. (2) Bed leaving situations. (3) Rehabilitation conditions. (4) Caregiver presents. (5) Socializing related situations (TV watching, speaking). Fig. 2 depicts the configuration of the real-world smart ward (Rm. 9A03 in NTUH). Until the end of 2011, we have collected data for 12 complete independent cases of situational data, all of which are elders whose age is over 65.

5.2 Preliminary Satisfaction Assessment

To assess the satisfaction of the functionality and usability of our system, we conducted a questionnaire-based preliminary survey from nurses and nurse practitioners in NTUH. The questions are all around the two applications mentioned in the previous section, and was mainly designed for assessing the level of satisfactory on the original demands. That is, the agreement that the system indeed helps monitoring overall patient conditions. 22 respondents (2 males, 20 females) are interviewed, whose age ranges from 23 to 51. The survey result of the 22 interviewees is briefly summarized in Table 1. The item that directly relates to our goal is the second one, which gets an average score of 4.14, which indicates an agreement on the system usability (5 for total agreement), and effectively represents a positive assessment of our system of satisfying the need of helping caregivers monitoring patient situations. However, the overall satisfaction of the system as a whole is not quite as good. By interviewing the respondent deeper, they generally think that the system will be more probable when serving chronic patients than acute ones. The main reason is that caregivers serving acute condition patients tend to be busier, and to whom the system can be less instantly affective. As a preliminary survey, we believe that the reply is encouraging. In addition, we have learned many precious suggestions from medical professionals.

5.3 Lessons Learned

Experience shows that deploying and maintaining a caring system in a real-world environment is never an easy task. In the following, we report several issues and lessons learned we have encountered and learned so far regarding to a caring system in real-world smart wards.

Dealing with sensor malfunctioning: In real-world deployment, sensors used to gather context data fails periodically and must be replaced. Unfortunately, due to privacy and health issues, it is impossible for the technicians to enter the

Table 1. Summary of preliminary satisfaction assessment

Question Item	Average Score
Be satisfied with operations of UI	4.09
Be provided with better understanding of patient conditions	4.14
Be satisfied with overall system functionality	3.91
Think that the system can be used clinically by now	4.23

*1 for totally disagree; 5 for totally agree.

wards and fix the failed sensors when they are malfunctioning. Currently, we configure the sensors so that they send heartbeats periodically. In addition, we use redundant sensors to reduce the overall MTBF (Mean time between failure).

Dealing with power insufficiency: All devices need power, either AC or batteries, to keep on operating. As it is very difficult to ask clinic caregivers to replace the battery, AC is a better choice. Unfortunately, AC-based power supplement limits the location of sensors which is critical for the accuracy of situation inference. In addition, the government law also restricts the deployment of the length and numbers of additional wires. As a result, we suggest that the number of sensors should be as small as possible. Besides, the circuit of the environment should be customized to alleviate the power supplement issue.

Dealing with noises coming from the environment: Situation recognition mechanism can be inaccurate due to noises coming from the environment. For instance, we have deployed a sound sensor in the toilet for analyzing flushing sound. However, due to poor sound insulation, the sensor not only collects the sound of neighboring wards, but also collects the sound of the nearby aisle, corrupting the overall recognition accuracy. We suggest to carefully find the potentially source that the noise coming from, and then use more types of sensors to help increasing the accuracy. In the above-mentioned scenario, we introduce two motion sensors so that the recognition module only activates when someone is entering the toilet.

6 Conclusion

In this paper, we present preliminary results of the design and evaluation of a situation-aware caring system for real-world smart wards in NTUH. The architecture is designed so that the applications built based on the system is extensible. In addition, the system is capable of supporting hierarchical situation inference from simple contexts. Currently, we have implemented the system as well as two applications and then deployed them in a smart ward. Based on the preliminary survey results, we have learned many precious suggestions from medical professionals and observed that there are still many challenges regarding to users' satisfaction. Currently, we are improving the system usability and conducting the survey at a larger scale. In the future, we will also enhance the autonomy and reduce cost so that it can be widely deployed. In addition, we are also planning to integrate the system with a private cloud platform in the hospital to facilitate more interesting applications.

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Testing Classifiers for Embedded Health Assessment

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Abstract. We present an example of unobtrusive, continuous monitoring in the home for the purpose of assessing early health changes. Sensors embedded in the environment capture activity patterns. Changes in the activity patterns are detected as potential signs of changing health. A simple alert algorithm has been implemented to generate health alerts to clinicians in a senior housing facility. Clinicians analyze each alert and provide a rating on the clinical relevance. These ratings are then used as ground truth in developing classifiers. Here, we present the methodology and results for two classification approaches using embedded sensor data and health alert ratings collected on 21 seniors over nine months. The results show similar performance for the two techniques, where one approach uses only domain knowledge and the second uses supervised learning for training.

Keywords: in-home sensing, eldercare monitoring, health alerts.

1 Introduction

Our view of embedded health assessment is the on-going assessment of health changes based on an individual's activity patterns and baseline health conditions. Sensors embedded in the environment are used to collect activity patterns for the purpose of early detection of health changes. Early detection is the key to promoting health, independence, and function as people age [1, 2]. Identifying and assessing problems early, while they are still small, provides a window of opportunity for interventions to alleviate problems before they become catastrophic. Older adults will benefit from early detection and recognition of small changes in health conditions and get help early when treatment is the most effective. Most importantly, function can be restored so they can continue living independently.

Recently, there has been an increased focus on the application of technology for enabling independent living and healthy aging. A recent review of health related smart home projects [3] included 114 relevant publications, with 71% of the projects including technologies for functional monitoring. The outcomes that have been assessed include in-home activity and restlessness captured using passive infrared (PIR) sensors [4][5], or video [6]; activities of daily living (ADLs) captured by multiple sensor types [7] [8]; sleep patterns captured using PIR motion sensors [9],

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bed mats [10][11], or load cells [12]; and walking speed using PIR sensors [13], video [14], radar [15], or depth images [16]. The variety of work in this area shows the interest and potential of the embedded health assessment approach.

A major challenge for classifier studies in this area is the capture of ground truth data sufficient for training and testing purposes. For example, students have been enlisted to act out ADLs to create labeled data sets, often used for studying statistical activity recognition methods, e.g., [8][17]. Other work has used much smaller datasets from a few volunteers, such as the statistical predictive algorithm to model circadian activity rhythms [18], mixture model analysis to infer activities of one user, validated with a manual log [19], and fuzzy rules used to classify activities in the home [20]. The difficulties associated with collecting longitudinal sensor data along with real health data of subjects have hindered studies on embedded health assessment.

In this paper, we present an example of unobtrusive, continuous monitoring in the home for the purpose of embedded health assessment, to address the management of chronic conditions as people age. An embedded sensor network collects data on activity patterns. A simple, one-dimensional alert algorithm is used to generate health alerts to clinicians in a senior housing facility. Clinicians analyze each alert using an electronic health record (EHR) and an interactive web interface for visualizing the sensor data. They then rate the clinical relevance of the alert. Here, we use the ratings as ground truth for health changes and test multi-dimensional approaches for classifying alerts as good or poor. Results are shown for 2 classifiers using embedded sensor data and health alert ratings collected on 21 seniors over nine months.

2 Sensor Network

Fig. 1 shows the sensor monitoring system for embedded health assessment. Data from sensors installed in seniors' apartments are logged and stored on a secure server. A typical installation for a one bedroom apartment consists of about 12 motion sensors, a bed sensor, and a temperature sensor for capturing stove and oven activity. PIR motion sensors are used to capture motion in a room area and also for localized activity, e.g., in the refrigerator, in kitchen cabinets, on the ceiling over the shower, and on the ceiling over the front door to detect apartment exits. The PIR motion sensors, which use the wireless X-10 protocol for data transmission, generate an event every seven seconds if there is continuous motion. This is used as an artifact to capture activity level in the home by computing a motion density as motion events per unit time. For example, a resident with a sedentary lifestyle may generate only 50 motion events per hour, whereas a resident with a very active life style may generate 400 or more motion events per hour [21]. A pneumatic bed sensor [11] is installed on the bed mattress and used to capture sleep patterns. The bed sensor generates events for restlessness in bed (four levels) as well as low, normal, and high events for pulse rate and respiration rate. For those residents who often sleep in a recliner chair, the bed sensor is installed in the chair. Sensor networks with motion, bed, chair and stove sensing have been deployed in senior apartments since 2005. Automated monitoring is used to detect the absence of sensor data, e.g., in the case of battery failures. However, there is still some data loss due to the brittleness of the X10 transmission.

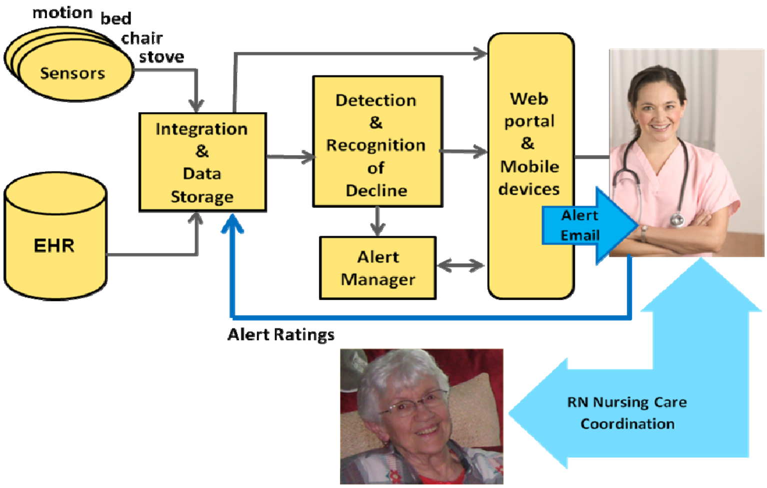

Fig. 1. Integrated sensor network with health alerts and ratings on clinical relevance captured from clinicians.

2.1 Health Alerts

The logged sensor data are automatically analyzed, looking for changes in an individual's data patterns. If a change is detected, an alert is sent to clinicians in the form of an email. The alert email includes two web links. One is a link into the web portal which facilitates fast access to the sensor data for the resident, showing a two week window of data before the alert and supporting an interactive interface for zooming out, drilling down, or displaying other parameters. This provides context to the clinician and helps determine whether the alert is relevant for this resident from a clinical perspective. The second link provides access to a feedback web page that allows the clinician to rate the clinical relevance of the alert on a five point scale, from 1 (not clinically relevant) to 5 (very clinically relevant). This rating is then used as ground truth on health changes to aid in the further development of the alert algorithms. On average, the clinician takes about two minutes to display the sensor data, analyze the alert, determine whether action is warranted, and provide feedback. For the study reported here, 4 clinicians provided feedback (one physician and three nurses), based on their clinical expertise with older adults [22].

2.2 Alert Parameters

The alert algorithm was developed through collaboration with clinicians and was intentionally designed as a simple algorithm to cast a wide net so that critical health changes were captured even if it resulted in a high percentage of false alarms. The approach looks at the sensor values per day, compared to a moving baseline of two weeks immediately before the day examined, i.e., relative sensor values are used rather than actual counts. The two week moving baseline was chosen on the recommendation of clinicians after retrospective analysis, as a compromise to capture both sudden and gradual health changes [22]. Each resident has a personalized *normal* that is reflected uniquely in the sensor data patterns, depending on the chronic health condition(s), the usual lifestyle pattern, the size of the apartment, and the number of sensors. This strategy of change detection has facilitated the testing of health alerts even in a diverse group of seniors with varying levels of health and chronic ailments.

Table 1 shows the alert parameters and sensor data monitored for the health alerts. For each parameter, the system computes a mean and standard deviation for the two week baseline window. If the current day's values vary from the mean beyond a pre-determined number of standard deviations, an alert is generated. The standard deviation multiplier varies somewhat for different behaviors, according to the research team's view of the relative importance of the parameters. Relative changes are computed for three time periods: (1) a 24-hour day, midnight to midnight, (2) daytime, 8am to 8pm, and (3) nighttime, midnight to 6am. The email alerts generated include the parameter that caused the alert, the time period of the change, the direction of change (increase or decrease), and the number of standard deviations from mean (how big is the change).

With this one-dimensional strategy, about half of the alerts generated are false alarms. Through manual investigation, it appears we are capturing nearly all of the obvious health changes; however, it is difficult to tell how many potential alerts we are missing. Nonetheless, capturing a clinical rating on the health alerts has allowed us to create a unique dataset for investigating more advanced algorithms for health alerts beyond this simple one-dimensional approach.

Table 1. Alert parameters and sensor data monitored for the alerts.

Alert parameter	**Sensors**
Bathroom Activity	Sum of motion sensor events in the bathroom (bathroom, shower, laundry)
Bed Restlessness	No. of all bed restlessness events
Bed Breathing Low/Normal/High	No. of bed breathing low/normal/high events
Bed Pulse Low/Normal/High	No. of bed pulse low/normal/high events
Kitchen Activity	Sum of kitchen motion sensor (kitchen, fridge, etc.) events and stove/oven temperature high
Living Room Activity	No. of living room motion sensor events

3 Classifier Methodology

We have investigated different classifiers for determining whether a particular day's sensor data should be classified as an alert day or not. The health alert ratings provided by the clinicians are used as ground truth in training and testing. Here, we discuss the application of two classifiers to this problem. The first is a fuzzy pattern tree that does not require training but rather takes advantage of domain knowledge from our clinical partners. The second is the support vector machine which uses training data and supervised learning to train the classifier. These classifiers were chosen for the study to provide a comparison between the use of domain knowledge vs. a trained classifier that supports a nonlinear decision boundary.

3.1 Feature Space

In analyzing the health alerts generated for the parameters listed in Table 1, it was observed that some of the parameters do not typically cause alerts and others generate a few alerts but not enough to be used for supervised learning. At this point in the study, there were also very few decrease alerts. Thus, in the end, we looked at the increases in the following four alert parameters: bathroom activity, bed restlessness, kitchen activity, and living room activity. If increased changes (the current day's count compared to the baseline period) are considered for all three time periods (daytime, night time, and full day), the dimensionality of the feature space is 12. Fig. 2 shows a PCA reduction of the 12-dimensional feature space, where blue indicates the good alert days and red indicates the bad alert days; as shown, there is not good separation between the good alert and bad alert classes. After further analysis of the alert ratings and discussion with our clinical partners, the feature space was reduced to consider the following six features as relative sensor values: increased nighttime activity in the living room, kitchen, and bathroom, increased full day activity in the bathroom, and increased bed restlessness at both nighttime and during the full day. A PCA reduction of this 6-dimensional feature space is shown in Fig. 3. Normal days (i.e., poor alert days) tend to cluster, and the abnormal days (good alert days) tend to be outliers around the cluster center. We report the methods and results using these six features.

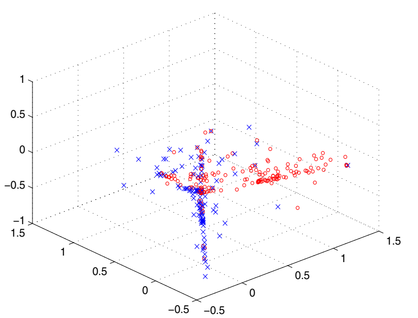

Fig. 2. PCA reduction of 12-D feature vectors from the health alert study. Red are poor alert days; blue are good alert days as rated by clinicians.

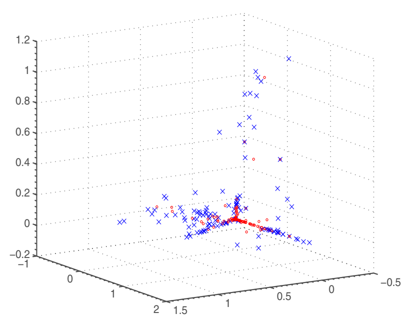

Fig. 3. PCA reduction of 6-D feature vectors from the health alert study. Red are poor alert days; blue are good alert days as rated by clinicians.

3.2 Fuzzy Pattern Tree

A fuzzy pattern tree (FPT) [23] was investigated as a method that uses domain knowledge only and does not require training. The six features described above were combined in a FPT using an OR operator, providing a "rule" that is easy for clinicians to interpret. Intuitively, the output is as follows:

IF	Bathroom activity for the full day is an Increase
OR	Bathroom activity at night time is an Increase
OR	Bed restlessness for the full day is an Increase
OR	Bed restlessness at night time is an Increase
OR	Kitchen activity at night time is an Increase
OR	Living room activity at night time is an Increase
THEN	Alert is Clinically Relevant

Gaussian-based membership functions were used for the input parameters. The Yager t-conorm [24] was chosen as the OR operator to explore the additive combination of parameters as opposed to the standard maximum. That is, if small changes were observed in several parameters, these resulted in a cumulative effect in determining whether an alert was warranted. The Yager parameter w sets the degree of optimism (how much greater the output is over the standard maximum operator) when two inputs are OR-ed together. For the work presented here, $w = 3$ generated the best classification experimentally.

3.3 Support Vector Machine

The support vector machine (SVM) was also tested to investigate a supervised learning approach. We investigated both a linear and radial basis function (RBF) kernel (using Matlab functions). We also tested both the 12 features and the six features described above. The RBF kernel performed slightly better than the linear kernel. The performance of the 12 features and six features was almost identical. The results reported here and compared to the FPT are the RBF kernel with six features.

4 Results

The FPT and SVM classifiers were tested with a set of health alert ratings spanning nine months on 21 senior residents. Table 2 shows the number of alerts used for each alert parameter that were rated as either good alerts or poor alerts. Good alerts included the alerts that were rated as a 4 or 5 (clinically relevant or very clinically relevant). The poor alerts included those rated as a 1 or 2 (not clinically relevant or less clinically relevant). The alerts rated as a 3 were interpreted as being neutral and were not included in this test but will be included in future work.

Fig. 4 shows the ROC curves of the two classification methods using the six features described in Sec. 3. The FPT was constructed with domain knowledge only as described above. The SVM results reported here use a RBF kernel and were evaluated with 10-fold cross validation. The performance of the two classifiers, as shown in the ROC curve, is very similar. Both achieved about 85% correct classification at the highest rate. As shown in Table 2, the percentage of good alerts using the one-dimensional alert algorithm was less than 40%. Thus, the multi-dimensional classifiers performed significantly better.

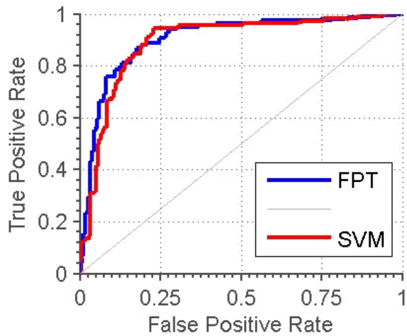

Fig. 4. ROC curves for the SVM and fuzzy pattern tree (FPT) using 6D feature vectors

Table 2. Health Alerts Used for Testing

Alert parameter	Good alerts	Poor alerts	Total
Bathroom Activity	42	43	85
Bed Restlessness	57	21	78
Kitchen Activity	7	63	70
Living Room Activity	17	85	102
Total	116	183	299

5 Conclusions

In this paper, we present work on testing two classification approaches for detecting early health changes. The ground truth was taken from health alert ratings provided by clinicians at a senior housing facility in which embedded sensors monitor seniors in their apartments. The two multi-dimensional classifiers tested include a fuzzy pattern tree that uses only domain knowledge of the clinicians and a support vector machine trained by supervised learning. Both classifiers achieved about 85% correct classification compared to less than 40% for a single-dimensional algorithm. In future work, we will explore other classification methods and test different baseline time periods. To improve over the current performance, we will investigate on-line learning using the alert ratings as feedback. The work presented in this paper shows that domain knowledge could be used as an initial classification scheme to build up enough data to support on-line learning methods.

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Stakeholder Involvement Guidelines to Improve the Design Process of Assistive Technology

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Abstract. The Mobile Phone-based Video Streaming (MPVS) system has continually been improved following interaction and evaluation with the relevant stakeholders primarily lay users, trial managers and developers. Following on from these evaluations, a user interaction framework was extended to provide guidance relating to the selection of information elicitation techniques during all stages of technology development. This framework may be employed when planning assistive technology development in order to achieve a technology-driven, yet user-led, methodology that permits informed decision making based on real needs, requirements and feedback.

Keywords: Stakeholder Involvement, Assistive Technology Development.

1 Introduction

More than 1% of the global Gross Domestic Product is spent on care for people with dementia (PwD) [1]. A potential way to curtail these costs is to utilise assistive technology to maintain independence and reduce carer burden. While a range of assistive technology is already available, a common issue with many of these systems is the deficit of information from clinical evaluation that relates to their impact on quality of life, independence and carer burden [2]. Although developing technology for PwD is a challenging task, it is crucial to perform user-driven development based on the needs, requirements and capabilities of the user. Nevertheless, it is often difficult to effectively elicit such information, as reliance on user needs assessment may overlook opportunities to develop truly holistic systems.

Regulative bodies have embraced the concept of user-driven technology design, providing recommendations for involving users during system development [3]. Shah *et al.* [4] investigated the type of professional and lay user involvement methods that should be employed according to the current stage of development: (1) *Concept Stage* (ideas generation), (2) *Design Stage* (prototype development), (3) *Test Stage* (in-house testing, clinical evaluation), (4) *Production Stage* (technology fabrication) and

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(5) *Deployment Stage* (target market release). Within the literature, PwD and their carers have had successful involvement at various stages; creating wish lists during the Concept Stage and Design Stage [5] and clinical evaluation in the Test Stage [6]. Nevertheless, the literature provides no clear guidance regarding the most appropriate approach to user involvement in order to obtain the most appropriate information.

This paper presents a framework for developers of assistive technologies to identify suitable information elicitation methods based on the information type and the current stage of development.

2 Assistive Technology Development Methodology

The MPVS system is a reminding technology that delivers scheduled video reminders to PwD via a mobile phone [7]. During development, a mixed methods approach was applied throughout the Concept and Test stages, which combined interviews, workshops, questionnaires, observations, cognitive walkthroughs and task analysis [3]. Formal ABA and longitudinal evaluations were conducted to assess usability, functionality, effectiveness, utility and benefit. Young controls, older controls, PwD and carers were involved, resulting in the views of 72 participants.

Based on the model developed by Shah *et al.* [4], and insights gained during the development and evolution of the MPVS system, three different classes of information that may be elicited from the user were identified: (1) Prior Attitudes, comprising attitudes to the technology or interventions that are independent of the technology itself, (2) Impact Factors, which are user specific factors that may be used to inform the development of the technology and (3) Technology Assessment, featuring the outcome of the assessment of the technology. Furthermore, for each of these classes, several subcategories of user information were defined, leading to a total of 12 types of user information relevant to assistive technology development.

When assessing Prior Attitudes, the *Perceived Ease of Use* and *Perceived Utility* may be determined. Technology adoption is highly dependent on these attitudes. It has been shown that if users don't identify the potential utility of a technology, or are apprehensive about 'learning' to use it, then they are unlikely to adopt it [8]. Table 1 presents a decision matrix for selecting elicitation methods for Prior Attitudes.

Table 1. Information Elicitation Methods Decision Matrix for Prior Attitudes

<table>
<tr><th></th><th>Concept</th><th>Design</th><th>Test</th><th>Deployment</th></tr>
<tr><th>Perceived Ease of Use</th><td rowspan="2">Brainstorming
Expert/User Meeting
Focus Group
Interview
User/Developer Workshop</td><td>Cognitive Walkthrough
Interview
Task Analysis
User/Developer Workshop</td><td rowspan="2">Beta Test
Focus Group
Interview
Questionnaire</td><td rowspan="2">Focus Group
Interview
Questionnaire</td></tr>
<tr><th>Perceived Utility</th><td>Interview
User/Developer Workshop</td></tr>
</table>

During technology development, the scope of the system should be initially determined within the Concept Stage and refined during the Design Stage. It is thus necessary to identify Impact Factors, including *Personal Factors*, such as age, cognitive and physical ability, *Environmental Factors*, such as infrastructure or the regulatory environment, *Requirements* and *Latent User Needs*. Such information will help inform the functionality and design of the system. Table 2 provides a decision matrix of suitable methods for the elicitation of Impact Factors.

Table 2. Information Elicitation Methods Decision Matrix for Input Factors

<table>
<tr><th></th><th>Concept</th><th>Design</th><th>Test</th><th>Deployment</th></tr>
<tr><td>Personal Factors</td><td>Brainstorming
Ethnography
Expert/User Meeting
Focus Group
Interview
Observation
Task Analysis</td><td>Cognitive Walkthrough
Interview
Task Analysis</td><td>Focus Group
Interview
Questionnaire
Think-Aloud Methods</td><td rowspan="2">Ethnography
Focus Group
Interview
Questionnaire</td></tr>
<tr><td>Environmental Factors</td><td rowspan="2">Brainstorming
Cognitive Walkthrough
Ethnography
Expert/User Meeting
Focus Group
Interview
Observation
Task Analysis
User/Developer Workshop</td><td>Cognitive Walkthrough
Interview
Task Analysis
User/Developer Workshop</td><td>Beta Test
Focus Group
Interview
Questionnaire
Think-Aloud Methods</td></tr>
<tr><td>Requirements</td><td>Cognitive Walkthrough
Interview
Lab-based Test
Task Analysis
Usability Test
User/Developer Workshop</td><td>Questionnaire</td><td></td></tr>
<tr><td>Latent User Needs</td><td>Brainstorming
Cognitive Walkthrough
Expert/User Meeting
Focus Group
Interview
Observation
Task Analysis</td><td>Cognitive Walkthrough
Interview
Task Analysis
User/Developer Workshop</td><td></td><td></td></tr>
</table>

Once a prototype has been developed, the desired information focuses on the technology's ability to satisfy the established user requirements. When acquiring information for Technology Assessment, *Fitness for Purpose*, *Usability* and *Satisfaction* unveil important information that can be used to determine how well the requirements have been met, along with areas for improvement. Once the technology has been finalised, information obtained from Technology Assessment, including the *Effectiveness*, *Utility* and *Perceived Value* of the technology, can be utilised in order to perform health economics analysis, thus leading to potential recommendation by regulatory bodies. Table 3 provides a decision matrix of elicitation methods suitable for Technology Assessment.

Table 3. Information Elicitation Methods Decision Matrix for Technology Assessment

<table>
<tr><th></th><th>Concept</th><th>Design</th><th>Test</th><th>Deployment</th></tr>
<tr><td>Fitness for Purpose</td><td></td><td>Lab-based Test
Usability Test
User/Developer Workshop</td><td rowspan="2">Beta Test
Focus Group
Interview
Questionnaire
Think-Aloud Methods
Usability Test</td><td rowspan="5">Focus Group
Interview
Questionnaire</td></tr>
<tr><td>Usability</td><td></td><td>Lab-based Test
Usability Test</td></tr>
<tr><td>Satisfaction</td><td></td><td></td><td rowspan="4">Beta Test
Interview
Questionnaire
Think-Aloud Methods</td></tr>
<tr><td>Effectiveness</td><td></td><td></td></tr>
<tr><td>Perceived Value</td><td></td><td></td></tr>
<tr><td>Utility</td><td></td><td></td><td>Interview
Questionnaire</td></tr>
</table>

3 Summary

Following on from evaluations performed during the development of the MPVS system, the user interaction framework by Shah, *et al.* [4] was extended to provide guidance relating to the selection of suitable methods for information elicitation throughout the various stages of development. Subsequently, the resulting framework can be employed when developing assistive technology in order to achieve a technology-driven, yet user-led, methodology that leads to informed decision making based on real needs, requirements and feedback.

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Comparison and Complementarity of Two Approaches to Implement AAL Systems

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Abstract. This short paper compares two approaches of the state of the art, to implement Ambient Assisted Living (AAL) systems. By comparing the two approaches, we aim to show that combining them could lead to an improvement of the offered response of the system. It shows that it could be interesting to develop a proof-of-concept system from a combination of these approaches, as it would improve the state of the art in AAL systems.

1 Introduction

Ambient Assisted Living (AAL) systems can denote the use of smart home systems to improve users' well-being. Services provided by indoor AAL systems can be classified in three subdomains [1]: *a) emergency treatment services* predict, detect, or prevent unsafe situations by propagating alerts in emergency situations, *b) autonomy enhancement services* provide tools to postpone the need of assistance by health caregivers or relatives, and *c) comfort services* to enhance the quality of life.

To develop such systems, users and deployment environments specificities should be taken into account, including user-specific diseases and acceptability, target platforms, target environment configuration, needs evolution, or environment dynamicity. We claim that, in order to be able to manage all these specificities, AAL systems for the elderly should be *customizable*, *distributed*, *adaptive*, and *heterogeneous*. AAL systems should be customizable in terms of provided services and target platforms to fit individual needs and deployment environments. They should provide distributed access points (for medical staff or relatives) and distributed implementation for security and quality of service. They should change their behavior and adapt their architecture to users and their environment. Adaptation may be related to evolution of elderly needs, either for a short or a long time scale, and may be a consequence of unanticipated evolutions in deployment environments or of changes in user health conditions. Finally, the heterogeneous

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nature of AAL applications is a consequence of their distribution. The capabilities of each target platforms must be taken into account.

This article compares two state of the art approaches that target those four goals: the "agent-based context-awareness" approach [2], and the "cloud component" approach [3]. The approaches are presented respectively in §2 and §3. Finally, §4 compares them and studies how they can be complementary on some points.

2 Agent-Based Context-Awareness

In the Agent-based Context-awareness approach (ACa) [2], agents are context-dependent [5]: to interact, they consume, process and publish context. This context-driven model supports autonomic agents in the open smart environment with mobile users [2], and the network neighborhood N_a of each agent a can change with time and location.

Agents are deployed on host components and categorized as either standard or user (domain-specific). User agent a only interacts with its own context space S_a, a context repository containing knowledge, queries for context, responses to such queries... from the perspective of a. The context space of H, S_H, subsumes $\forall a \in H : S_a$. Standard agents on H implement H's services, have full access to S_H, the underlying hardware and external components. Context describes requests for context, rules to manage $\forall a(S_a)$, operations on context and user agents themselves. Adaptors interface with foreign services. H maintains $\forall a \in H : N_a$; updates to the environment's hardware, deployment of agents and their withdrawal are implicitly discovered and dynamically integrated.

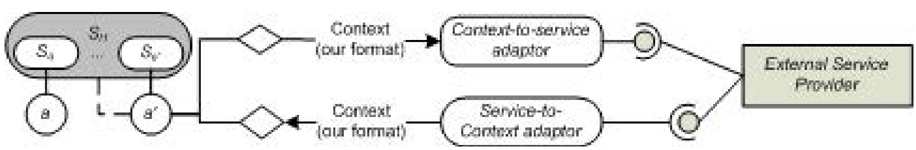

Fig. 1. Service-to-Context adaptor (example)

No orchestrator agent is needed. As a only knows S_a, it can act alone. If $a_i, i \neq 0$ finds no suitable context provider, it can still produce context based on S_{a_i}. Agent-based Context-awareness is inherently resilient; the unavailability of some agents does not necessarily impact system behavior.

3 Cloud Components Approach

The *cloud component approach* (CCa) is dedicated to component based-distributed systems [3]. Traditionally, components are localized on nodes, and bindings hold distribution, implemented for instance using web services. Unlike the common scheme, a Cloud Component (CC) instance is distributed among nodes and inter-CC bindings are local to nodes. To be distributed among nodes, each CC is composed of multiple sectors, which are units of deployment and have multiplicities that constraints the number of instances they may generate [3].

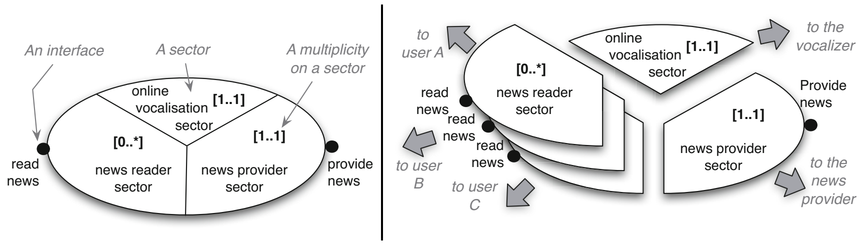

Fig. 2. Cloud component for the case study (left), and a sample deployment (right)

This particularity in the distribution of CCs offers numerous advantages for the specification of distributed architectures. Firstly, as remote bindings are made internal to components, non-functional properties (NFPs) held by those bindings become the responsibility of the component. Secondly, implementations of CCs can be distributed among sectors. Thirdly, all the services may be provided in a ubiquitous way. Indeed, interfaces are held by the border of the CC, and are reified on each sector (fig. 2). In addition to the *CC model*, and to organize the variability, the CC approach also defines a generative approach [4] for the components, namely the *Model for Variable Refinement Processes* (MVRP) [3]. Each feature of the desired CC is implemented using a model transformation that refines its model. The rationale of this approach lies in the fact that not only features are reified as code, but so are variabilities. For instance, if a target runtime platform has the capability to migrate a data repository, this variability is also reified as code in charge of the adaptation. Therefore the final product is truly an adaptive distributed application.

4 Complementarity of the Approaches.

This section shows how the ACa and CCa may complement one another in many respects. The four criteria we use to compare the approaches are customizability, distribution, heterogeneity and adaptability. Table 1 evaluates those criteria.

First, we notice that the CCa guides the design of distributed component systems and helps developers organize interactions, whereas the ACa model relies on a run-time organization of agents. Indeed, the CCa can be used at design time to generate ACa architectures dedicated to runtime. *Customizability* refers to the capability to be tailored at design time, in terms of architecture, implementation, or provided services. The CCa complements the ACa, as it brings

Table 1. Approaches complementarity

	Cloud Comp. & MVRP	*Agent-Based Context-Aware*
Global approach		
Targeted step	Design time	Runtime
Base concepts	CCs, features	Agents, Context
Dev. methodology	Models, MVRP	Framework-based
Customizability	Based on the MVRP	*n/a*
Distribution		
Deployment units	CCs/Sectors	Hosts/Agents
Intra-communication	Based on sub-components	Context-based.
Heterogeneity	*n/a*	Based on adaptors
Adaptability	Structural variabilities.	Volubility of the context.

variability at design time through the MVRP. *Distribution* refers to the capability to provide distributed services. This includes mechanisms used for the management of distributed nodes' life cycle, the management of communications and the reachability of nodes. Again, the approaches complement each others as sub-components defined at design time with CCa could be represented by agents at runtime, and that internal communications could be abstracted by sub-CCs and reified as host context spaces. *Heterogeneity* refers to the capability to be deployed in environments in which the deployment nodes offer lower layers that provide similar but not equivalent services. The CCa abstracts underlying platforms, and therefore does not represent heterogeneities at design time. In ACa, heterogeneity is handled by adaptors that convert heterogeneous resources to context. *Adaptability* is similar to customizability, but happens at runtime, whereas customizability happens at design time. ACa offers native adaptability at runtime as part of the context model, whereas the MVRP models variability. The two approaches are fully complementary for this criterion. For example, user agents, being context, can move from host to host. On the other hand, an MVRP can represent multiple variants of positions taken by sets of agents and help design the possible adaptations.

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Smart Documents for Home Automation

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Abstract. This work describes the use of well known computer applications to enable smart home users to monitor and control their homes using customized documents. Middleware written in applescript and perl-cgi was used to integrate the computer applications with the OpenWebNet protocol used in home automation. The events triggered by the applications are easily log by web and mail servers to facilitate diagnostic operations and their archival. This software was tested on the implementation of "The Smart Door Project" to remotely manage door access, monitor the door and archive the events. One of the features is that the door opens after the user receives an e-mail with the magic words "Apriti Sesamo" in the subject field, and "Alibaba" in the text.

Keywords: Applescript, Domotica, Home Automation, Middleware, OpenWebNet, System Integration, Smart Door, Smart Home, Wiki Server.

1 Introduction

With the evolution of home automation, there is an increase in complexity due to the large number of systems, modules, sensors, scenarios, displays, options, and features. Ideally, commands are simple clicks; but in smart homes, there is a large variety of commands, ranging from physical keys in walls close to appliances, to remote virtual keys and gestures in mobile devices, plus many scenarios triggered by a variety of events. Therefore, there is a need for a well maintained documentation containing a detail list of instructions for the house on what to do during the opening or closing operations, when going to sleep or awakening, while enjoying the home theater, etc. These instructions must deal with the settings of the zones (rooms and areas) and systems (lighting, irrigation, climate control, sound distribution, and burglar alarm). In addition, this instructions should be adapted for different users (kids, adults, and seniors).

Every manufacturer provides user manuals and a remote control for easy operation of their equipment; but it is possible to end up with many manuals and remote controllers, at least one for each brand of equipment in the several areas of the home. Also, users get information from the web by googling for solutions to frequent problems; therefore, there is a need for an integration between the information and the functionality of the home devices. Today, most automated homes have one or more computers connected to the internet; and, it is possible to use wiki[1] applications to

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save, manage and search specific home information like documents, inventory of the components, list of service providers, maintenance and operating instructions, detailed pictures, glossary and index for easy reach; but, a software middleware [2] is needed to make all the home automation modules in the house available as objects to be inserted and used by applications in the computer.

It is the purpose of this work to describe how to use common applications, to control a home by interacting with documents provided by installers and modified by users. For example, the search for a received e-mail containing the instructions for opening the house enables the user to modify it and resend it to her/himself; with objective that the computer executes the instruction list after receiving the e-mail.

2 Smart Documents

The following subsections describe the applications tested in the creation of smart documents for home automation.

2.1 Mail. Using Mail Rules for Automations

Most digital documents allow users to send an e-mail with preset fields with a single click. In our case we send an e-mail with the Subject “Apriti Sesamo”, and a body message containing the “magic” word “Alibaba”. The receiving Mac computer at home filters the received e-mail, using the Rules features in the Mail application, and runs an applescript after checking all fields (sender, recipient, subject, and magic word in content.) Below, there is an example of a 2-line applescript to open the door by closing a contact for 0.5 sec, using an OpenWebNet[1] command sent to the home controller and playing a message saying “the terrace door is OPEN”:

```
do shell script "echo \"*1*18*72##\" | nc 10.0.0.82 20000"
tell current application to say "The terrace door is OPEN"
```

If you would like to try the applescript above, it will have to be customized for the switch OpenWebNet command (*1*18*72##), and the IP address of the My Home BTicino[2] gateway. Most e-mail services today support secure SSL to encrypt messages, in this case the text Alibaba; and they move selected e-mails into folders for later retrieval.

2.2 iCal. Calendar Events and Reminders to Schedule Automations

It is possible to have repetitive events and reminders in iCal[3] (Apple’s calendar application). Each event and reminder entry have one or more alarm fields to specify a sound, send e-mails and/or run a script at a specific time and date. The iCal application can be used to track our scheduled appointments organized by categories,

1 OpenWebNet is a protocol standard for home automation.

2 My Home BTicino is a home automation product of Legrand Group.

3 OS X Server, Mac OS X, MacBook, iMac, Preview, Pages, Numbers, Keynotes, Mail, iCal iTunes, iBooks, iBooks Author, Applescript, Automator, Mac, iPad, iPod and iPhone are Trademarks of Apple Inc.

therefore, home automation commands can be scheduled in a category. For example, on our anniversary, an event lights up the color LEDs in the hall and play the romantic Playlist in iTunes. The same process is possible for the summer irrigation and climate control.

The server has a middleware consisting of applescripts used by the events and reminders to execute automations as alarms. Below, there is a 2-line applescript to schedule a repetitive command using iCal in Mac OS X:

```
do shell script "echo \"*1*16*57##\" | nc 10.0.0.82 20000"
Tell current application to say "irrigation ON for 15 minutes"
```

If you would like to try the applescript above, it will have to be customized for the switch OpenWebNet command (*1*16*57##), and the IP address of the My Home gateway. Use the AppleScript Editor to help with the creation of the applescript. Save and name your applescript with a name like irrigate.app and close the editor to start the iCal application. Edit the iCal event fields: time, repeat, country time zone, etc. One of the alarm fields should contain the applescript irrigate.app. Other alarm fields may be used to send e-mails, warning signals, etc ... before or after the event. We can even use an alarm field to start iTunes with the music preferred by a user during the irrigation time.

2.3 Wiki. A User Web Interface for Home Automation

Most house computers come with a web server application included to service web requests from the local area network and Internet; that, users can access through a variety of browsers. The Wiki Server is a type of web server used for collaboration that enables users to create and publish their own wikis, blogs and podcasts. These web services are useful to communicate and collaborate with friends, co-workers, and family members. The wiki server manages the access to the information contained in the wiki pages and shows documents according to user and group permissions, and their enabled services: calendar and blog. Users are required to login in before accessing the wiki pages. The wiki pages display the specific commands, web cam images, and text and photographs.

A wiki document may contain live images from network cameras, making it easy to check a room, to see if the lights and shutters are working fine. Family members and some friends may have access to external views of the home, to get an indication that the exterior lighting and irrigation system are properly working, while the owners are on vacation. The server enables the use of virtual private networks (VPN) to allow mobile devices to access home information remotely as if they would be in the local network at home. The Wiki application is useful for people that need to delegate the monitoring of a patient remotely while limiting the devices controlled by the delegated person. Each wiki has a folder containing a limited number of .cgi files with commands for the home controllers.

Mail, iBook, iTunes, Keynotes, Numbers, Pages, and Preview documents can contain hyperlinks to .cgi files in a server; enabling the user to control her/his home using a simple click while reading the document, playing a presentation, or even listening to music! A click on a URL sends a request to the HTML server to execute a .cgi file. The CGI-Executables folder in the server contains a list of possible .cgi files with scripts containing command lists to control home switches.

3 Smart Door Implementation

There are several automations to open a door remotely, and to turn ON a light when a person approaches a front door. However, in our implementation in Florence, Tuscany, there are synergies among the automation systems, the network camera, the computer at home, the e-mail application, and the motorized lock. The IR sensor triggers the automation to welcome visitors by turning ON the light and ringing the front door bell. When the light goes ON, the network cameras sends an e-mail with the image of the area around the door. The home owner receives the e-mail and she/he forwards the message to her/himself after adding the keyword, in this case "Apriti Sesamo". The computer activates the motorized lock using an OpenWebCommand sent by an e-mail Rule after checking the sender, subject and content fields of the received e-mail. All the e-mail involved in the process are saved and archived.

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Proposed Generic Method to Assess Efficiency of Smart-Walkers

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Abstract. This paper is proposing a method to assess the efficiency of smart-walkers. These robotic devices are closely interacting with the human user. As we address mainly the needs of elderly people we chose to base our method on normalized geriatric medicine tests. We are showing the feasibility of that approach on robuWALKER device.

Keywords: elderly people, walking aids, robots, Geriatric assessment, method.

1 Introduction

With the increasing number of elderly people in our society, the need for useful assistive devices is rising. An effective walking has to fulfill several criteria: be usable, efficient, stabilizing and of low energy cost to the user. These criteria are strongly linked. A pathological walk will be more expensive in terms of energy and a fall more likely occur. The ideal device should supply a mechanical support and be able to adapt itself to the environment and to the incapacities of the user. A robotic device may be an answer. Mechatronic systems, here smart walkers, allow additional functions such as: helping the user to get up or to sit down, to avoid an obstacle, to help in orientation, driving, etc… The existing systems are research prototypes, except PAM-AID which was marketed under GUIDO™ [1]. Most of them were tested in order to validate their features either on healthy adult subjects [2], or on the elderly, [3], [4]. Only PAM-AID was tried on its usability [5].

This paper is proposing a method to assess the efficiency of smart-walkers. We compare the use of robuWALKER (rW) [6] by four healthy senior volunteers and four elderly patients with some level of motor and cognitive impairment. We are comparing the efficiency of rW using the time of task completion and the fit between the human and rW according to the observation of the recorded videos.

2 Material and Method

The smart-walker used is the rW composed of 2 driving rear wheels and 2 caster wheels at the front. It has two motorized arms to help the elderly to stand from seated.

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rW is allowing forward and backward motion, right and left turn and rising and lowering the handles. 2 buttons on the handles are offering the 3 functionalities.

The objective of the protocol is to estimate the main technological benefits derived from the project. The technical aid (rW) is assessed with two normalized geriatric tests for frailty and walking difficulties. These two are the 4 meters walking test (4M) [7] and the Timed Get-up and Go test (TGG) [8]. The 4 meters walking test measures the time for an elderly person to walk 4 meters, after 2 meters' run up. In the Timed Get up and Go, a chair is facing a wall 4 meters away. The tester is first telling the volunteer he will have to stand, walk to the wall, come back, go round the chair and seat down again. The chronometer is started with the order to stand and stopped when the volunteer is seated again. Thence the TGG consists in a succession of basic mobility tasks: getting up from a chair – walking- turning round- walking back to the chair – going round the chair – sitting down. If the volunteer failed the 4M, the protocol would stop at that stage. Failed 4M was considered as taking over ten times more time to complete the test with the tested device then walking the usual way (i.e.: with no aid or a different aid to a walker).

We included people with both motor impairment (as assessed by 4M over 4sec and TGG over 13sec) and cognitive impairment (as assessed by MMSE –Mini Mental State Examination– below 26). The recruiting was not random. In the case of the cognitively impaired, the consent was also given by the main caregiver. No participant was under legal protection. All participants consented in being filmed and allowed films to be used for the purpose of the research.

3 Results

Nine persons were included in the protocol: five healthy volunteers aged 71 to 86, four impaired volunteers aged 83 to 96. One healthy volunteer proved to have walking impairment with 4M at 5.7sec and TGG at 19sec. As she had no cognitive impairment she was excluded from analysis. One impaired volunteer had improved with MMSE = 26, 4M at 3.28 and TGG at 12.24 and thus requalified as healthy volunteer.

Fig. 1. Forward leaning with increased double limb support -Walk with the handles down -Sandwiched between robot and chair

One elderly could not walk the 4M with rW. She could not use the right button to go in a straight line and was tending to turn to the right. After nearly 2 minutes she still could not reach the arrival line and was stopped. Most subjects appeared to lean forward during the use of the robot with an increased double limb support (Fig.1.).

While getting up, subjects tend either to: first move the handles to high position then stand, or walk with the handles at knee level. When the user wants to turn, they may either turn sharply and with the back wheel leaving the ground, or move in a wide arc (having to go back and forth when in front of the wall).

4 Discussion

Our small population is representative of the handicapped elderly population and their caregivers; with a sex ratio towards the female both in the caregivers and the elderly people. The fact one volunteer had to be excluded from the healthy group and one had to be moved from impaired to healthy; is reflecting the prevalence of frailty in the population of elderly caregivers and the possibility of reverting impaired people from the status of impairment to a status of frail or even prefrail [9].

We have observed that both in the healthy and the impaired, the 4M durations are close using the usual way or walker. In patients, rW duration is double (apart for one who failed the test) to 3 to 5 times in the healthy. It may be that people with impairment are closer to their spontaneous speed than the healthy; could that lesser difference be a benefit index?

In the TGG the difference between the usual way and the walking frame is already important, between a half and twice more. It is then increasing again with the rW from six to ten times more than in the usual way in five volunteers, but only twice for the two who had the greatest impairment but still succeed. We think the sharp increase in those less impaired from a motor point of view could be related to the use of the interface when turning at the wall and around the seat. For the two others, the better stability provided could have balanced the usability of the interface.

We observed various behaviors. Some users would bend forward and usually increase their double limb support, occasionally with the rear wheel (or in case of the regular walking frame the rear feet) leaving the ground. We guess the user has to push the walker: either that it is useless or resisting too much (walker) or that the motorization speed is to low (rW). Handles are set level with the hips during use of a walker. When getting up with a human help; the caregiver will at the same time pull and rise his arms. With rW there are two buttons involved: one to raise the arms and one to go forward; it appears that the two buttons were probably not used concurringly. Turning in front of the wall proved difficult. It could be that a walker is causing a difficulty in guessing the required trajectory to clear the wall. Yet we only observed the problem with the rW. As the rW is using the space norms for manual wheel chairs, the difficulties are more likely related to controlling the speed and direction of the rW than to its volume.

More than one camera will be needed in the coming experiments as it is a hard to focus on areas of interest (such as hands, wheels…) and assess general aspects (such as trajectory, distances to different markings) at the same time. Moreover, dead angles due to the robot and the body may limit the assessment of the user-robot couple.

Another option would be to increase the number of tests for each volunteer. This would allow reaching an optimal training. But should face practical issues in that population: tiredness, daily habits (such as naps, meals), and availability for the tests. As an addition, when possible, it could be interesting to have the feelings and feed backs from the volunteers; to help with issues such as the resistance felt when using a walker or the usability of the control interface.

5 Conclusion

This paper proposes a methodological frame using normalized geriatric medicine tests to assess smart-walkers, as compared to regular walkers, for use by elderly people. We applied this approach to the rW with four healthy and four impaired (motor and cognitive) elderly volunteers. Completion times and empiric observation where used. We expect to refine the method by using more viewing angles and focusing on aspects such as trajectory, lifting of wheels, tilting of user's body, duration of double limb support. Interviews could then help with perception by the users.

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A Usability Protocol for Evaluating Online Social Networks

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Abstract. Online Social Networking (OSN) has become one of the biggest successes of the Internet. Facebook is the most popular service with over 800 million users. OSN have the potential to combat feelings of social isolation amongst the aging population. This study has investigated how people with differing levels of experience using OSN, within different age categories, are able to interact with the core features of Facebook. The goal has been to identify concessions and produce guidelines for designing an OSN for older people. This paper presents quantitative findings from a usability study which utilized eye tracking to observe 20 users' interactions with Facebook. The usability issues that were encountered and how these may be addressed to help older people with social isolation are discussed.

Keywords: Social Isolation, Web 2.0, Online Social Networks, Facebook, Usability, Eyetracking.

1 Introduction

The Internet has provided significant gains in terms of enhancing people's knowledge, entertainment, social communication and collaboration [1]. These have all been enriched by the widespread adoption of Web 2.0 technologies. Web 2.0 has become a major platform for supporting communication, sharing and collaboration on the Internet. According to Murugesan [2] "Web 2.0 is a collection of technologies, business strategies and social trends". Common Web 2.0 technologies include Blogs, RSS Feeds, Social Tagging, Mashups and OSNs.

Facebook [3] is regarded as the most widely used OSN with 2011 statistics showing 800 million active users [4]. Facebook's core aim is to allow people to feel more connected to each other by allowing them to share the details of their private life as a means of socialising with other Facebook friends.

2 Usability of Online Social Networks

Usability plays a key role when considering user acceptance of Web 2.0 content and is used to assess how 'easy' interfaces and systems are to interact with [5]. An

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interface can take the form of a website, a rich Internet application or any other content presented from which usability testing can be undertaken. Nielsen, states that usability is made up of five quality components [6]: learnability, efficiency, memorability, errors and satisfaction. To test these it is best to complete a usability test. A common approach is the 'Think Aloud' technique where a participant talks about what they are thinking and doing as they complete the tasks [7], [8]. In addition to traditional usability techniques, eye tracking can be used to ascertain what people look at on websites and make better design decisions as a result [5].

3 Using Online Social Networks to Combat Social Isolation

An estimated 23% of the population of the UK will be aged over 65 by 2034 [10]. At a European level, this figure is almost set to double by 2060 [11]. With such a rise in the elderly population there will be an inevitable increase in long-term conditions such as chronic pain, cardiovascular diseases and most notably dementia.

Approaches to support improved communication and interaction could reduce, for example, levels of depression and feelings of isolation [13]. It is believed that there is merit in hypothesising about the benefits older people could gain from participating in Web 2.0 based OSN to communicate with friends, family and caregivers [14]. Both Shapira *et al.* [15] and Goswami *et al.* [16] reported that older people have a greater sense of empowerment through online interpersonal interactions helping maintain cognitive functioning and the characteristics of OSN making it easier and cheaper for older people to keep social ties active to enhance feelings of social connectedness.

Nevertheless, there are a number of inherent challenges, not least, that according to the office of national statistics in 2011 which has shown that only 18% of over 65's use an OSN compared to 91% of those aged between 16 and 24 [17].

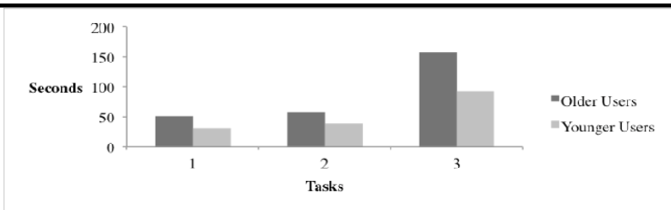
4 Method

A Usability Study of Facebook was conducted during December 2011, which included the new interface called 'Timeline'. All participants had never previously used this version of Facebook. They were invited to undertake a number of predefined tasks within a generic user account (update status, send a message and upload a photo). Verbal protocols (think aloud) were collected and observational data was used to identify usability problems. Eyetracking was used to derive eye movement patterns. Twenty participants (9 Male, 11 Female aged from 22 to 65) took part in the study, giving consent to be included via ethics approval granted from University of Ulster.

5 Results

Each participant was asked to complete a series of tasks, which was provided to them in a scenario-like format on pre-setup Facebook accounts. The tasks included: (T1) Reflect on the new Timeline, (T2) Making a status update, (T3) Posting onto a friend's Facebook page, and (T4) Upload a photo. Over ninety percent of the tasks were completed by participants. The time taken to complete individual tasks varied, however, on average Tasks 2 and 3 resulted in completion times of 44.15s and 45.15s respectively. In Table 1, the time difference for task completion between the user groups below and above 35 years old are presented. On average, it took the older participants 20 seconds longer to complete all tasks.

Table 1. The time difference of older and younger users to complete tasks



	Older Users			Younger Users		
	T2	**T3**	**T4**	**T2**	**T3**	**T4**
Mean	51s	57s	157s	31s	38	91s
CI Lower	39s	48s	125s	19s	29s	59s
CI Upper	62s	65s	188s	42s	46s	123s

6 Discussion

Within this study the latest version of the Facebook interface referred to as Timeline was tested. All participants had never used this feature before, regardless of their previous Facebook usage. Quantitative data obtained following evaluations unveiled that 90% of participants who undertook the study had a positive experience and reported that they 'enjoyed' using Facebook. On average 69% found the interfaces normal, easy or very easy to understand and over 50% agreed that it was attractive.

Participants were asked to interact with Facebook for three tasks to complete various scenarios. Of the 60 planned tasks across all participants only 3 were not completed. This is positive, however, it does not provide a full insight into the evaluations. Users often had miscues whereby they progressed in the wrong direction only to realise their error, stop and return to the task. Younger participants enjoyed exploring the new functionality, however, the older participants were worried about making mistakes. As one participant expressed: *"oh I am going back to the start again as I think I have done the wrong thing*. This shows older participants worried about making the wrong decision and breaking something.

The efficiency times of the tasks were also taken and based on these it was found that on average task 2 and 3 had similar response times. This could be due to the fact that a status update and posting on a friend's wall even though sounding different are in essence the same task and the same functionality is used to complete them. Nevertheless, the most significant aspect of our study was when we split the age groups and found that on average the older users spent an extra 20 seconds completing the tasks.

It can be inferred that older users' usability of OSN is not being met and the study enlightens us that even experienced users do not use many advanced interactions. Generally, participants stated they made status updates and uploaded some photographs, the rest of the time they observed friends' social lives just to keep up to date and connected.

7 Conclusion

To conclude, in this paper we have shown the potential of Web 2.0 technology and OSN to help alleviate the problem of social isolation. Results from the study conducted demonstrated that while most participants enjoyed using Facebook it was found that older users took longer to engage with the interface. Older users have more difficulty and the usability issues they encounter could be addressed with a new progressive design. A methodology the authors will use in the future to conduct the evaluations and improve its interface design. This will involve looking at what older people currently do on the Internet and how we can adapt the Interfaces using Web 2.0 technology to suit their needs.

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A Smart Home 3D Modeling Approach for Spatiotemporal Analysis

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Abstract. Indoor location systems allow for the integration of more and more daily life objects into the smart home environment model. Consequently, managing the spatiotemporal data of things is becoming increasingly challenging. In this article, we propose a 3D geometrical approach to spatiotemporal object management and analysis based on the adaptation of the spatial database concept. We use the DOMUS apartment at Université de Sherbrooke as a reference environment for 3D modeling of smart homes. We present a sample of 3D spatial analysis functions implemented in the DBMS to illustrate the use of the geometric model in providing smart home indoor location-based services.

1 Introduction

Smart homes are complex systems that provide personalized services to the occupants for their well-being. Personalization is based on environmental context awareness and is linked to activities of daily living. Traditionally, context makes extensive use of the location-based service model. Geographic information systems (GIS) and spatial databases are at the core of this model. However, the geographical approach fails when directly applied to indoor environments because of precision and representation issues.

Spatiotemporal information management and analysis can be still achieved using a spatial database, but the environmental model and the tools for analysis must be revised, adapted, and supplemented to fit the large scale 3D nature of homes. This paper presents a 3D geometrical prototype based on a topological representation of space to manage the spatial model of a home environment used for context building, real-time spatiotemporal analysis, and environmental services.

2 Indoor Location-Based Services

The field of GIS has been at the forefront of location data management for many years. GIS applications are used to store, analyze, manage, and visualize geographical data. However, the GIS approach is limited by two factors when it comes to indoor spaces: the scale of the model and the 3D representation. First, indoor space management comes with a need for much greater precision

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than GPS-based systems can provide. Second, indoor spaces like smart homes are poorly served by 2D geographical models. Cupboards, drawers, chairs, and rooms are linked in complex 3D relationships that must be preserved in a system, if we are to use it to provide adapted services to a person at home such as locating a specific cookware, redirecting the computer output to the most visible screen, or managing lighting and heating based on the location of the person.

3 Spatiotemporal Representations and Analyses

Three approaches were considered for spatiotemporal representation and analysis of indoor environments in this research. First, computer-aided design tools such as AutoCAD from Autodesk, virtual reality tools and gaming engines were evaluated. They all support advanced 3D modeling and real-time environment manipulations. However, they lacked explicit spatial analysis capabilities to perform ad hoc relationship computations and the ability to customize the description of spatial objects [2]. Second, spatial ontologies were considered. Ontologies can be used to support context-based reasoning for smart home services [5]. This approach has been used for spatial description or inference computation on outdoor, indoor, and virtual environments. However, ontology-based computation suffers from severe performance degradation when ontologies reach a large size. Hybrid approaches combining ontologies with spatial indexing have been research specifically to address this issue [3]. Maintenance and update may also represent a challenge as objects are moved frequently in the home environment. The geometric spatial database was finally studied. Though the concept of spatial database emerged in the field of GIS, it is not restricted to it. Most spatial DBMS can accommodate for both geographical (based on a datum) and geometrical (flat surface) data representation. An object-relational schema is used to store spatial objects and their descriptions. 2D support is a standard feature of spatial DBMS. Some can also be extended to support 3D geometries [6].

We found that spatial databases have been overlooked as a working ground for 3D representations and spatial analyses in smart home development. This paper focuses on this approach. We built a complete 3D indoor smart home environment model based on a geometric reference and extended the PostGIS/PostgreSQL DBMS to support basic 3D spatial analyses.

4 The DOMUS Smart Home Database

4.1 DOMUS Home Spatial Model

The DOMUS Laboratory contains a fully equipped experimental apartment with sensors and effectors [4]. The basic 3D model of the apartment was created from the university architecture department's AutoCAD file and stored in PostGIS 1.3.5 for PostgreSQL 8.3. Cupboards, appliances, and the furniture were manually measured and added in the database using simple spatial INSERT statements. Objects in the apartment are represented as rectangular volumes

(a) 3D Model (b) DOMUS Lab

Fig. 1. Comparison between 3D model of DOMUS Lab and the reality

corresponding to their 3D bounding boxes. Objects are stored through the multipolygon geometry primitive while enforcing manually the definition of the third dimension. Technically, a closed 3D object is represented by six polygons, one for each side of the volume, assembled in a collection and stored as a single instance in the database. Our model was visually compared with the real-life spatial configuration in the apartment (Figure 1).

4.2 Spatial Functions

The most visible limitation of the geometric DBMS approach in supporting smart home services is the lack of implemented 3D spatial functions such as equality, inclusion, intersection, adjacency, and overlap. Between-objects spatial 3D operators are not implemented in PostGIS. However, the DBMS approach provides a standard way for function development and use within the database environment. Borrmann and Rank [2], through the 9-intersection model, have identified over 50 different spatial relationships relevant to 3D spatial models between the four basic types of spatial objects (points, lines, polygons, and volumes).

To overcome the functional limitation, operators for proximity, inclusion, adjacency, and intersection were implemented for volume-to-volume objects in PostGIS/PostgreSQL through the standard procedural language. We also extended spatial analysis to include buffer creation around an object (select around), size comparison between objects (can fit into), spatial relationship characterization (top of, in which room) to represent typical queries used by smart systems when providing services.

Our database approach is aligned with the need for contextual information, i.e. the identity of the entities, the location of entities and the time where the information is relevant [1]. Furthermore, the object-relational DBMS model allows for the customization of the description of objects in standardized database table fields. This allows for a detailed custom description of objects in the smart home environment. One can store characteristics of an object at different levels of generalization for efficient retrieval and analysis.

5 Spatial Services in the Smart Home

The current project takes the form of a JAVA based reporting dashboard prototype to monitor real-time and historical spatial relationships between chosen objects. The application lets the user specify interactively a relationship to monitor between two or more objects in the database for a specific time frame and create alerts. The alerts are raised when the relationships proves to be true. Current experiments use simulated spatial data to validate the effectiveness of the approach.

6 Conclusion

We provide a new approach to manage indoor spatial data through a geometric 3D representation of the smart home in a spatial object-relational DBMS. As a proof of concept, we implemented a set of spatial functions to support spatial relationship analyses within the DBMS. We were able to demonstrate the validity of the approach through the implementation of a spatial dashboard to monitor activities in the DOMUS smart apartment. Applications of the work for smart homes include objects locationing, travel distance calculation, historical environmental state replay and spatial reasoning.

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Integration of HL7 Compliant Smart Home Healthcare System and HMIS

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Abstract. Smart Home Healthcare Systems requires interoperability at different levels for effective provision of healthcare. Patients should be monitored regularly by medical doctors, whereas, medical doctors are themselves busy. Medical data exchange is extremely important for monitoring healthcare ubiquitously using smart home systems. Lack of standards usage such as HL7 for medical information exchange limits the usability of these smart home healthcare systems. Therefore, the need is to provide an interoperable solution in which smart home healthcare system and Hospital Management Information System (HMIS) can exchange information to provide guidelines to the patient. The proposed system caters this deficiency in smart homes by standardization the health related information and communicating it with HL7 compliant HMIS for the physicians to provide guidelines. Sensors data in raw form is initially converted to XML form and then converted to HL7 CDA document. This data is communicated to HMIS for physicians to evaluate data and provide recommendations. The proposed system ensures effective monitoring of patients health data and timely information exchange among Smart Home and HMIS to ensure effective treatment and management of patient disease.

Keywords: Smart Home, HL7, HMIS, Interoperability, Sensors.

1 Introduction

The demand for best available healthcare is on rise due to increase in chronic diseases in the population [1]. An independent individual (more specifically ageing population and chronic or alzheimer's disease patients) are moving towards concept of smart homes equipped with advanced technologies to monitor their activities and detect health related problems earlier in order to get better healthcare. In order to achieve the vision of remote monitoring of patient's healthcare at smart homes, interoperable services are required among smart home systems and Health Management Information System (HMIS).

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This interoperability of smart homes systems and HMIS for sharing patients information with physicians requires practicing standards. HL7 Clinical Document Architecture (CDA) [2] is a standard that lies in HL7 family and is used to specify the structure and semantics of "clinical documents" for the purpose of exchange [2]. In smart home environment, the sensory data needs to be mapped to CDA format and communicated with HMIS. Therefore, it is necessary to have a system that make effective use of sensory data for interoperable exchange of the extracted information using healthcare standards.

The proposed system is based on HL7 compliant Smart Home Healthcare system, that filters raw sensory data to extract health related information and transform it in HL7 CDA format; communicates the information with HL7 compliant HMIS. The physicians evaluates the information transmitted and responds with appropriate recommendations. These recommendations are communicated by HMIS with smart home system in return.

2 Human Activity Recognition Engine (HARE)& CDA

HARE engine is designed and developed by our lab for monitoring the activities of Alzheimer disease patients. HARE [3] focuses on monitoring human activities (Alzheimer's patient as case study) using heterogeneous sensor technology and intelligently processing these activities for analyzing the context of the activities performed. The activities of the Alzheimer's patients are recognized using motion sensors, video based, wearable sensor based, and location based sensors. These activities are intelligently processed by Context-Aware Activity Manipulation Engine (CAME). HARE has the capability to become part of the smart home environment and identify activities. The only weak link of the HARE engine is its ability to communicate these high level activities identified, with HMIS of a particular hospital where physicians can evaluate the results and accordingly provides recommendations/guidelines. The sensors data gathered, processed, and then filtered is made part of CDA document as observations. Our proposed system will transform the output into HL7 CDA format and communicate with HMIS compliant to HL7 CDA standard. This makes the interoperability among systems possible, as communicating systems interpret the data as desired and responds accordingly.

3 Proposed Architecture

The proposed system is based on HL7 compliancy to smart home healthcare system as shown in Figure 1. The detail of the components of the system is as follows:

3.1 Sensory Data Repository and Preprocessing

The health related information about the patient is mainly provided by the motion sensors. The data collected about the different activities are stored in

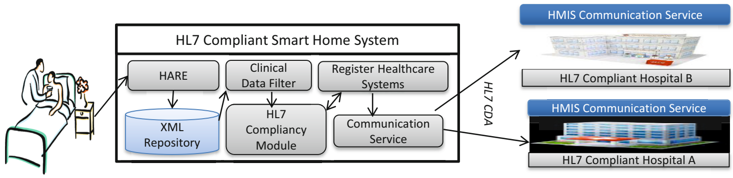

Fig. 1. Working Model

Sensory Data Repository. The data is obtained from different sensors. All the data stored in this repository is in raw form and requires pre-processing to communicate it with HMIS. This preprocessing is carried out using different algorithms that are proposed and implemented in our lab for sensory based [4], video based [5] and location tracking [6] activity recognition. We assume that the algorithms are applied on the sensory data has stored the preprocessed information in XML format.

3.2 XML Repository and HL7 Compliancy Module

This XML format records different activities of the patient. Each activity detected includes information about type of activity, sensor information that detects activity, name of the person, activity name, unique id of the sensor location and occurrence time of the activity. After every hour the smart home system needs to communicate this gathered information with the physicians of a particular hospital. The physicians that have agreed to monitor patients data continuously and provide recommendations, requires the data to be communicated with their HMIS. HL7 Compliancy module generates clinical document, transmitted to all the registered healthcare systems with smart homes.

3.3 Registered Healthcare Systems and Communication Service

This component is responsible for storing the information about the HMIS that requires the patient information to be transmitted to them on regular basis. After every hour the gathered data is transmitted to these HMISs in HL7 CDA document using Communication Service. This service is responsible for communicating information to and from Smart Home System to the HMIS's. The information obtained from the HL7 Compliancy module is transmitted to the desired healthcare systems.

4 Conclusion

The integration of smart home healthcare systems with HMIS is critical for treatment and management of patients. The vaccum of integration is filled by use of standards such as HL7 CDA. The use of sensory information and molding to CDA document for communication ensures exchange of medical information at the right time, resulting in improved patient health due to guidelines provision at appropriate time.

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Reaching Analysis of Wheelchair Users Using Motion Planning Methods

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Abstract. For an environment to be well suited for wheelchair use not only should it be sufficiently clear of obstacles so that the wheelchair can navigate it, it should also be properly designed so that critical devices such as light switches can be reached by the hand of the wheelchair user. Given a goal location, explicitly calculating a path of the wheelchair and the person sitting in it so that they can reach the goal is not a trivial task. In this paper, we augment a Rapidly-exploring Random Tree (RRT) planner with a goal region generation stage that encourages the RRT to grow toward configurations from which the wheelchair user can reach the goal point. The approach is demonstrated on simulated 3D environments.

Keywords: Wheelchair accessibility; Reaching analysis; Motion planning.

1 Introduction

The problem of reaching analysis is key to determining if an environment is properly designed for wheelchair use and is closely related to the problem of determining the possible collision-free motion of a kinematic device. A complete solution to the motion planning problem is known to be exponential in the robot's degrees of freedom (DOFs) [1] which makes the planning problem hard for sufficiently complex devices. Given the inherent complexity a number of heuristic approaches have been developed for motion planning problems with high DOFs [2]. The Rapidly-exploring Random Tree (RRT) [3] has proven to be useful for path planning for high DOF robots with non-holonomic constraints. The RRT builds a random tree in configuration space rooted at the start state of the vehicle. New nodes are sampled randomly from configuration space and connected to the tree. This process continues until either a path to the goal is found or if some predefined resource limit is exhausted.

This paper develops a method for the reaching analysis of wheelchair users to capture the behavior of the moving wheelchair as well as the moving arm of the person sitting in the chair in a 3D indoor environment. We develop a simplified mathematical model of a wheelchair as a differential drive vehicle and the human's right arm using a spherical shoulder joint and a revolute elbow joint. This kinematic structure is used to plan motions from an initial configuration to a goal configuration implicitly specified by the position of the hand using an RRT that has been augmented to probabilistically decouple the planning project into plans requiring motion of the base and pure reaching motions of the user. The planner can be a useful tool for clinicians to assess the reaching accessibility of wheelchair users in a given environment.

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2 Related Work

Given the similarities of the underlying problem, the methodologies developed for robot motion planning have been applied to the problem of simulating and automatic testing the mobility of wheelchairs before (see [4,5] for examples). In addition, much work has been done on capturing reachable workspace properties for humans [6,7,8]. [6] describes a simplified kinematic model of human arm motion and estimates the reachable workspace by calculating all combinations of values of valid joint coordinates. Another approach presented in [7] discretizes the workspace into equally sized small cubes. Into each cube a sphere is inscribed and sample points on the sphere are examined using inverse kinematics. The methodology introduced in this paper expands upon the work that uses a Probabilistic Roadmap Method (PRM) to estimate the reachable workspace of the wheelchair user described in [9]. Instead of using a PRM, here we use a modified RRT method to search a path for its appropriateness in handling the non-holonomic constraints imposed by the wheelchair device. The main disadvantage of the basic RRT search strategy is that it slowly covers the configuration space in order to reach the goal since the tree expands in all directions in configuration space until the goal is reached. A common approach to improve the performance of an RRT-based search is to bias the tree growth towards the goal configuration (RRTGoalBias) or a region around the goal configuration (RRT-GoalZoom) [3]. In this paper we exploit this second strategy informed by the details of reaching from a wheelchair platform.

3 Motion Planning for Wheelchair User

Let $\mathcal{A}$ denote the model of the desired kinematic structure moving in a 3D static Euclidean space $\mathcal{W}$. $\mathcal{A}$ consists of a mobile wheelchair base $\mathcal{A}_{base}$ and an attached kinematic chain that models the user's arm $\mathcal{A}_{arm}$. For simplicity we only consider the right arm in this paper, but the method can easily be extended to two arms. Let p_{goal} denote the goal point in $\mathcal{W}$, where the wheelchair user's hand should be placed after following a feasible motion from an initial pose c_{init}. Any configuration of $\mathcal{A}$ uniquely determines the position of the hand in $\mathcal{W}$. The objective is to have the arm reach the goal, that is $FK(c_{goal}) = p_{goal}$. The reaching analysis of the wheelchair user involves using motion planning techniques to determine a feasible motion, which is a sequence of configurations $(c_0, c_1, ..., c_n)$ that $\mathcal{A}$ can execute such that: $c_0 = c_{init}$, $c_n = c_{goal}$ and $FK(c_{goal}) = p_{goal}$; every configuration c_i on the path is collision-free and within joint limits; every connection of c_i and c_{i+1} is free and satisfies the kinematic constraints.

Consider a person in a wheelchair attempting to reach an object in the environment. It is likely that the person will move the wheelchair to an area close to the object first and then move the arm to reach the goal. Motivated by this observation a goal reaching region $\mathcal{C}_{goal}$ is generated around the location from which the user could potentially reach the goal and then we bias the growth of the RRT towards the goal reaching region. Let $\mathcal{C}_{goal}$ be the subset of the configuration space from which the arm is potentially able to reach p_{goal}. For a given goal point $p_{goal} = (x_{goal}, y_{goal}, z_{goal})$, $\mathcal{C}_{goal}$ is bounded by by configuration volume $[x_{goal} - r, x_{goal} + r] \times [y_{goal} - r, y_{goal} + r] \times [-\pi, \pi] \times \Phi_1 \times \Phi_2 \times \Phi_3 \times \Phi_4$, where Φ_i denotes the domain of joint ϕ_i. Given the potential goal region $\mathcal{C}_{goal}$

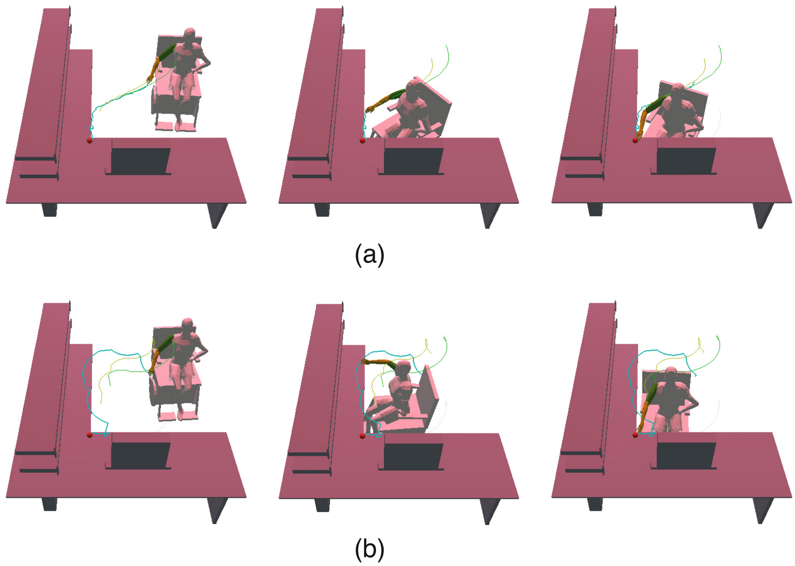

Fig. 1. Two paths found by the RRTGoalRegionBias planner. The goal location is identified by a red ball.

the goal-region biased RRT algorithm is used to find a feasible path from c_{init} to a goal configuration $c_{goal} \in \mathcal{C}_{goal}$ that satisfies its constraint $FK(c_{goal}) = p_{goal}$. The algorithm grows a single tree rooted at c_{init} to search the high-dimensional space. Here, we bias the growth of the tree toward $\mathcal{C}_{goal}$ to speed up the convergence by tossing a biased coin to determine which direction the tree should grow. Based on the coin either a random state in $\mathcal{C}_{goal}$ is chosen; otherwise, a random state in $\mathcal{C}$ is chosen. The choice of the bias can affect the efficiency of the path planner. A complex environment may require more bias towards random states in $\mathcal{C}$ to avoid local minima and to reach a good coverage of the space, and a relatively open environment may require more bias towards the potential goal region for faster convergence. Fig. 1 demonstrates two different paths found using this approach. In this example the random coin was balanced 50-50 between choosing points in $\mathcal{C}_{goal}$ or $\mathcal{C}$, so the wheelchair has equal chance to take a relatively direct path to the goal (e.g. Fig. 1(a)) or not (e.g. Fig. 1(b)).

4 Experimental Validation

The goal of the testing is to demonstrate the motion planner's ability to find paths to reach goal points in this complex environment. Table 1 shows the performance comparison of the brute force RRT and the approach described here (RRTGoalRegionBias) in six scenarios. It shows that RRTGoalRegionBias had a better success rate in finding a path than RRT. For the successful runs RRT generated larger trees than RRTGoalRegionBias. Finally the path length is recorded as the length of the trajectory the user's hand follows. RRTGoalRegionBias finds slightly shorter paths than RRT in 5 out of 6

Table 1. Performance statistics for six scenarios set in the simulated environment shown in Fig. 1 with various initial and goal specifications. Results are averaged for 100 independent runs for each scenario.

Problem		case 1	case 2	case 3	case 4	case 5	case 6
# Success	RRT	38	40	30	27	32	46
	RRTGoalRegionBias	100	100	85	91	87	80
# Nodes	RRT	10308	12267	11261	11527	10381	9941
	RRTGoalRegionBias	3556	3930	5938	7451	6708	7825
Path Length	RRT	665	860	921	739	843	837
	RRTGoalRegionBias	657	826	901	731	799	845

cases. It shows that our algorithm can find paths comparable to those found with a more exhaustive search using a naive RRT approach.

5 Conclusions

This paper describes a methodology for automatic reaching analysis of wheelchair users in an indoor environment. The methodology depends on the development of a simple model of a person sitting in a wheelchair and an efficient motion planner. The motion planner is based on RRT, which generates a potential goal region based on the point to reach first and then uses this region to bias the RRT to find a path. Experimental evaluation shows that the RRTGoalRegionBias planner is more efficient and effective than the basic RRT planner for this task. A tool has been developed to plan paths and to provide a visual display for clinicians to gain a better understanding of the wheelchair's performance in the workspace.

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Improving Telerehabilitation Technology to Challenge Chronic Disease Management

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Abstract. Demands for rehabilitation services, particularly in-home care and outpatient clinics, are increasing and are difficult to meet. In-home telerehabilitation is growing as a complement or alternative to face-to-face therapy. The technological aspect of telerehabilitation is in constant evolution and is central to a high quality and efficient way for rehabilitation delivery. The aim of this presentation is to demonstrate technological innovations used "in-home" with the telerehabilitation platform over the years (generations 1 and 2 of the technological infrastructure). The improvements made from the first to the second generation partly implied the use of external sensors to allow a real time follow-up of clinical parameters. These changes have permitted research and new studies to target new populations for teletreatment.

Keywords: Telerehabilitation, Technological environment, Platform.

1 Introduction

In-home telerehabilitation, defined as the provision of remote rehabilitation services to individuals with persistent and significant disabilities via information technologies and telecommunications in their home [1], is growing as a complementary or alternative intervention to traditional face-to-face therapy for in-home care and outpatient services. The rationale for in-home telerehabilitation is to expand and facilitate the delivery of rehabilitation services to people who cannot access them due to either a shortage of health care professionals or a lack of access to services, long waiting lists for home care services or problems getting to and from the clinic [2]. Contrary to teleconsultation which provides diagnosis and evaluation services, clinical care services provided via in-home telerehabilitation encompass active treatment and follow-up [3]. To ensure the quality of the rehabilitation and allow this novel method to deliver accessible services to as many populations as needed, with either acute or chronic diseases, the technological environments should be in constant evolution.

The main purpose of this presentation is to show technological innovations used in-home with the telerehabilitation platform in order to consider physiological parameters in the teletreatment of chronic obstructive pulmonary disease (COPD).

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2 Technological Infrastructure for Telerehabilitation Services

2.1 The First Generation of the Technological Infrastructure: Dealing With Acute Diseases

Based on experience from the past 10 years, a telerehabilitation platform was developed to deal with post-surgery patients (post-arthroplasty) who returned home after short-term hospitalization stays and needed rehabilitation in a short delay [4-6]. While being similar in many ways, two different systems were used to provide telerehabilitation services: an "in-home" system and a clinician system. The telerehabilitation platform for both systems is illustrated in Fig 1. The core of these systems is a videoconferencing system (Tandberg 550 MXP), which uses a h.264 video codec and integrates a pan-tilt-zoom (PTZ) wide angle camera combined with an omnidirectional microphone. The system is mounted over a 20-inch LCD screen, which displays the video received from the other end. Audio is played using external speakers placed on both sides of the screen. Video and audio data were encrypted and transmitted over a residential high-speed internet connection, allowing communication over a maximum bandwidth of 512 kbps in both directions. The system was also resilient to packet loss and ensured that audio and video were correctly synchronized.

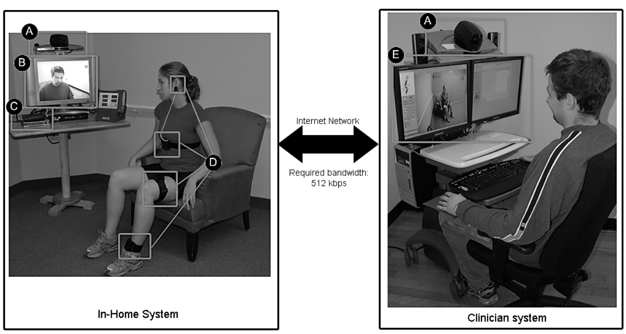

Fig. 1. First generation telerehabilitation systems. Components of both systems are: A) videoconferencing system, B) LCD screen, C) router and modem connecting to the internet, D) clinician computer and screen display.

On the clinician's side, a similar videoconference and network setup are used. However, since the clinician needs to have control over the session and cameras, a dual display computer replaces the LCD screen used at home. The control of sessions and cameras is provided with custom software developed specifically for the purpose of conducting such sessions. The platform was developed to ensure that interactions between clinicians and clients during the telerehabilitation sessions were not impeded by technology, but facilitated with user-friendly interfaces such as providing an intuitive control on both PTZ cameras (home, clinician), as described in Fig 2.

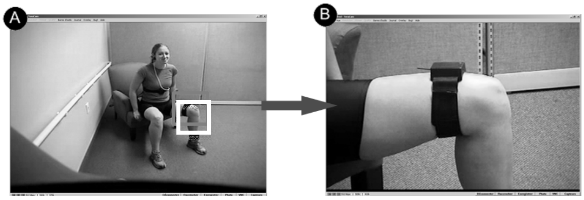

Fig. 2. Camera control. The camera control is entirely done with a mouse. On a click, the camera centers on that point. In A), the users select an area with the mouse and release the mouse button. The camera moves and centers on the area shown in B.

2.2 Second Generation of Technological Infrastructure: Dealing with Chronic Diseases

The first generation system was efficient in providing teletreatment to a population with acute diseases. However, teletreatment of chronic diseases such as COPD requires the follow-up of some clinical parameters in real time : oxygen saturation and heart rate. In order to allow connection of such external sensors**,** the LCD screen used in the first generation system was replaced with a 25.5-inch Touchsmart embedded computer. Sensory data is received and processed by the in-home computer, displayed on the patient's screen and sent over the Internet connection, providing a real-time display of the sensors to the clinician. The second generation of the telerehabilitation platform and software interface for both systems are illustrated in Fig 3. Currently, only an oxymeter is used with COPD patients, but the addition of an in-home computer allows the connection of other sensors such as respiratory belts, instrumented soles and inertial measurement units that could provide further information such as respiratory frequency, center of pressure and anatomical angles. Bandwidth used by these sensors varies according to their number, type and sampling rate. The oxymeter is currently sampled at 1 Hz and uses under 0.1 kbps, making it negligible compared to video bandwidth. The patient can also use the system during offline sessions to complete exercises or to watch informative presentations on COPD using a touch screen.

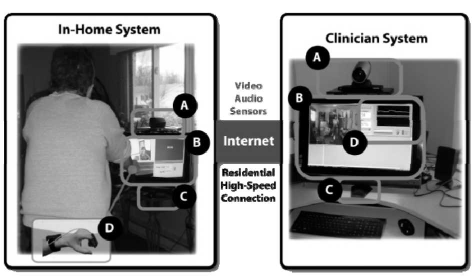

Fig. 3. Second Generation of the Telerehabilitation Platform. Components of both systems are: A) videoconferencing system, B) embedded computer with a touch screen, C) microphone and speakers, D) video and sensors display.

This second generation is already used in actual teletreatments. In fact, results of a pilot study on COPD is now published [7]. The main conclusion is that teletreatment seems to be a practical way, both clinically and technically, to dispense rehabilitation services for patients with COPD.

3 Conclusion

The research has shown that the use of a residential Internet connection is sufficient for in-home teletreatment considering the new possibilities offered by the second generation of the telerehabilitation platform. The use of external sensors, like the oxymeter, is promising and did not add any additional constraints. They seem to be appreciated by both the clinicians and the patients. Although more complex and a bit difficult to move, the use of a computer on the patient's side of the platform increased the possibility to follow by live transmission some physiological parameters essential for patients at risk of acute problems during the teletreatment sessions. In the future, other sensors will be incorporated in the platform depending on the populations and clinical needs (ergocycle, blood pressure, range of motion and force measurement).

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Rehabilitation Training and Evaluation with the L-EXOS in Chronic Stroke

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Abstract. This paper presents the results of the evaluation training performed in a group of chronic stroke patients using a robotic exoskeleton device. The effects of training were assessed both by means of clinical evaluation in terms of Fugl-Meyer and Modified Ashworth assessment scales and of functional evaluation, by means of Bimanual Activity Scale. Interestingly we found a significant improvement of both clinical and functional evaluation.

Keywords: Upper limb rehabilitation, stroke, virtual reality, robotic rehabilitation.

1 Introduction

Rehabilitation training in stroke performed with robot assistance can lead to significant motor recovery when the patient is actively involved with volitional effort in the exercise. A class of rehabilitation robots that deserve a particular interest in upper limb rehabilitation is constituted by active exoskeletons. Exoskeleton are robots with kinematic isomorphic to the human arm, that can be worn on the user arm. They present several significant advantages compared to end-effector based system [1].

The Light-Exoskeleton [1] is a right-arm rehabilitation robot used for stroke patients rehabilitation; it is composed of five degree-of-freedom (DoF), of which four active, i.e. shoulder and elbow flexion/extension, shoulder internal/external rotation and, abduction/adduction (**Fig. 1**(a)). In the simplest way the assistance provided by the robot can consist in a gravity counterbalancing of weight of the arm, as this has been proved to enlarge the workspace of the arm [2] and to be effective for motor recovery. Alternatively the robot can provide a guided assistance during task execution, according to an impedance-based model or more advanced controls [3]. In this work we present the results of a rehabilitation training performed on a group of chronic stroke patients, who underwent a rehabilitation training and assessment performed [4].

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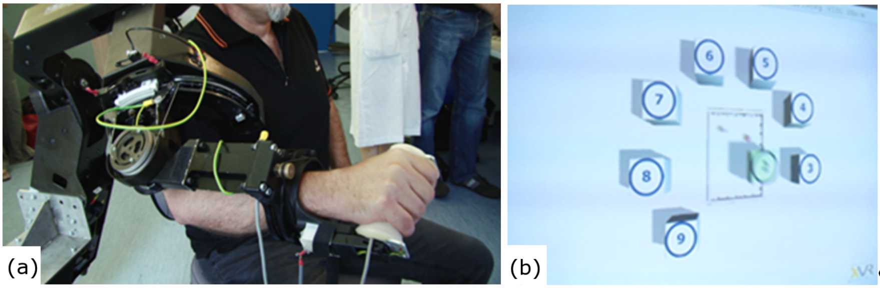

Fig. 1. (a) The L-Exos system (b) panel for the evaluation session

2 Material and Methods

Stroke survivors who volunteered to participate in the study were people who met the following inclusion criteria: aged between 18 and 80 years, able to understand the study purpose and procedure, and provide informed consent, moderate upper limb emiparesis. Seven patients with stroke event occurred at least six months ahead (2 females, 6 males, 62.9±9.9 years old) were enrolled in the treatment and scheduled to perform six weeks of training with three sessions per week.

At the enrollment and discharge of treatment patients underwent clinical evaluation performed with upper limb Fugl-Meyer Assessment Score (FMA, 66 pts) and Modified Ashworth Scale (MA, on 19 muscle groups), plus a functional assessment performed with a standardized test, the Bimanual Activity test, consisting in evaluating in terms of time and quality of movement (estimated on 0-4 scale) the execution by the patient of a set of ADL tasks requiring bimanual coordination. At the enrollment the average FMA assessment score was of 25.5±12.99 and the average MA of 11.88±9.96. Three out of seven patients underwent also a follow-up clinical assessment after 10 months since the end of treatment to evaluate the retention of regained function. Patients were administered a robotic training with the L-Exos system with training scenarios projected on a stereoscopic projection wall. The rehabilitation training consisted in two training exercises and one evaluation test, performed with the assistance of a robotic device. The first exercise consisted in a reaching task performed with an impedance assistance control.

The second training exercise consisted in a training scenario in which the patient has to compose a virtual puzzle with the gravity assistance only provided by the robot. The exercise was then followed by an evaluation session allowing to assess the performance in movement execution over different direction of space, since a set of target to be reached where placed in the vertical plane, along twelve possible positions arranged equally spaced along a circumference (**Fig. 1**(b)). Both smoothness and time of execution of movement were measured as indexes of performance by the robot in this evaluation session. Movement time was computed as the time to move from the start position in the centre to the target, while smoothness index was computed by counting the number of peaks in the velocity profile of movement.

3 Results

Paired student t tests were used to verify the statistical significance of analysis . A significant clinical improvement was observed. Clinical assessment at the end of treatment revealed an increase of FMA to 31.43±15.41 ($p<0.02$), with no significant change in spasticity (MA after treatment 10.57±7.52).

We observed a significant reduction of time in the execution of bimanual movement from 17.19±3.83 to 12.33±5.38 sec ($p<0.02$) with an overall increase of quality of movement from 1.99±0.77 to 2.79±0.92 ($p<0.03$). A similar trend was detected for the two indexes of performance measured with the robotic platform, with a marked decrease of movement time from 2.57±1.17 to 1±0.68 sec ($p<0.004$) and improvement of going from 6.9±1.19 to 2.51±1.8 ($p<0.003$), (**Fig. 2** (a)).

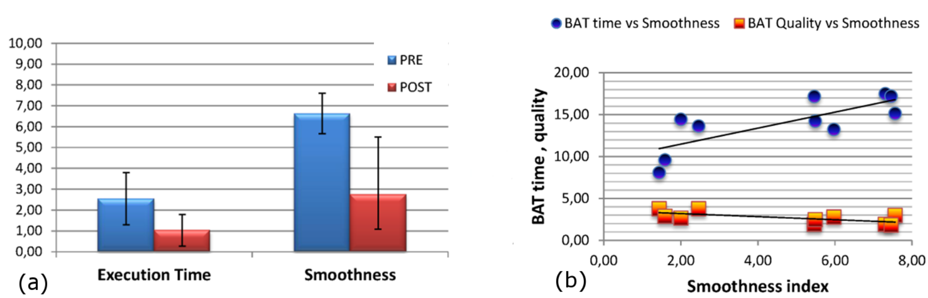

Fig. 2. (a) Assessment of movement performance with robot, (b) Correlation of bimanual activity index with smoothness of movement

We investigated the correlation of the functional indexes (Bimanual Activity Scale) with the robot assessment scale, to assess whether the improvement of performance observed with the robot was effectively transferred as ability to perform ADL activity. We found a strong correlation between the smoothness index and the time and quality of movement assessed with the Bimanual Activity Scale, as shown in **Fig. 2** (b) .

Moreover the performance improvement in movement execution was analyzed in terms of different directions of space by means of the robot-based assessment, by means of radial plots, shown in **Fig. 3**. It is possible to see from the picture how a marked and significant improvement is obtained mainly in the movements executed to reach targets in the ipsilateral space, while no significant improvement is obtained in the contralateral space.

Moreover in the small subgroup of patients that underwent a follow-up evaluation at month 10, we found a percentage improvement of FMA of 39% that was maintained also at the follow-up assessment, were still the 22%.

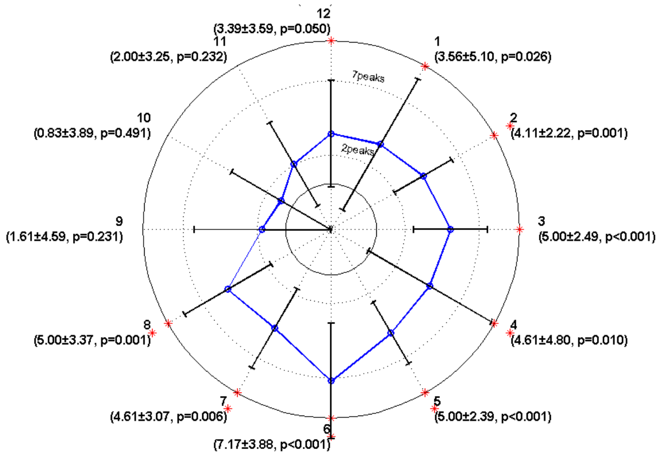

Fig. 3. Percentage improvement of smoothness index, ** p<0.01, * p<0.05

4 Conclusions

Confirming our previous results, we have found that the rehabilitation training might lead to different improvement of performance in the contralateral and ipsilateral space. Moreover we have found that the improvement in smoothness of movement represents a predictive indicator of both clinical assessment performed with clinical scale and also of regained ability to perform activity of every day life. This represents an important result, since it allows to directly map the measured performance to improvements into functional activity. The first preliminary results from follow-up evaluation performed at 10 months of distance since treatment, allowed us also to hypothesize that such a regain of function is preserved over time.

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Human Activity Recognition via the Features of Labeled Depth Body Parts

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Abstract. This paper presents a work on labeled depth body parts based human activity recognition. In this work, we label depth silhouettes for various specific body parts via trained random forests. From the labeled body parts, the centroid of each body part is computed, resulting in 23 centroids from each depth silhouette. Then from the centroids in 3D, we compute motion parameters (i.e., a set of magnitude and directional angle features). Finally, Hidden Markov Models are trained with these features and used to recognize six daily human activities. Our results show the mean recognition rate of 97.16% over the six human activities whereas a conventional HAR approach achieved only 79.50%. Our system should be useful as a smart HAR system for smart homes.

Keywords: Human activity recognition, random forests, labeled body parts, depth silhouettes, Hidden Markov Models.

1 Introduction

Human Activity Recognition (HAR) is an important area of proactive computing research due to its potential in understanding activity context from daily video recordings of human activities. Its applications include patient-monitoring systems, surveillance systems, health care systems, human machine interaction, and etc. [1]. The goal of HAR is to recognize outdoor and indoor activities from a video having a sequence of activity images. In typical video-based HAR, binary silhouettes of human body [2] have been widely used to get activity features. Recently, depth silhouettes are adopted providing richer information than the binary silhouettes [2]: body parts are differentiated by means of different intensity (i.e., depth) values. If each body part can be recognized in the depth silhouettes, much advanced HAR could be possible for complex human activities.

Recently, body parts recognition from depth silhouettes has become an active topic in human motion recognition. For instance, in [3], random forests (RFs) are used to label each depth pixel for its corresponding body part. In general, this approach requires multiple motion capture (MoCap) cameras and optical markers attached to a subject to create a database (DB) of depth silhouettes and corresponding pre-labeled body parts.

In this work, we propose a novel labeled body parts based HAR system. However, we first provide a way of creating such DB with a single depth camera (i.e., without MoCap

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cameras and optical markers), with which RFs are trained for body parts labeling. Secondly, the trained RFs are used to label every incoming depth silhouette into 23 body parts. Then, from the centroids of the labeled body parts, we estimate motion parameters as activity features. Finally, these features are used in Hidden Markov Models (HMMs) for HAR. We have tested our system over six human activities.

2 Methodology

The overall processes of our proposed HAR system is given in Fig. 1, showing key steps of body parts labeling via trained RFs, activity feature generation, and HAR via trained HMM.

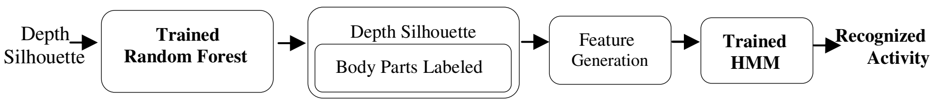
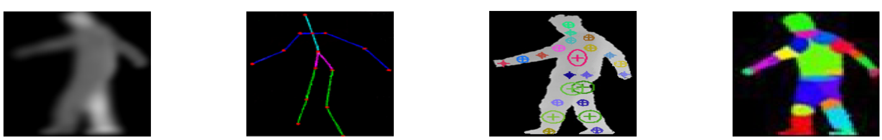


Fig. 1. Overall flow of proposed labeled body parts based HAR system

2.1 Labeled DB Generation

To label the body parts in the depth silhouettes via RFs, a DB is required as fore mentioned. Fig. 2 show how this DB is created. Fig. 2 (a) shows a depth silhouette, (b) a skeleton model derived from (a) with a vector of 15 joints of body parts. In Fig. 2 (c), each body part is represented with a Gaussian contours based on the information of body parts proportions and joint locations. Finally in Fig. 2 (d), each body parts are identified and denoted in different colors.



(a) (b) (c) (d)

Fig. 2. The DB generation processes: (a) a depth silhouette (b) its skeleton model of a walking activity (c) body parts representation with Gaussian contours, (d) classified body parts

To train the RFs, the generated DB in Section 2.1 is used as shown in Fig. 3.

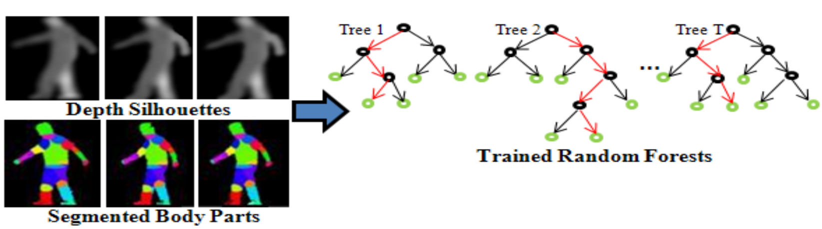


Fig. 3. Sequential flow of training trees using depth silhouettes and segmented body parts

2.2 Body Parts Labeling and Feature Extraction

With the trained RFs, incoming depth silhouettes are labeled into 23 body parts. Then, a set of 23 centroids gets computed from every depth silhouette of activities. Finally, from two consecutive sets of centroids, a set of motion parameters including motion magnitude and directional angles are obtained. The overall procedures of these body parts labeling and feature extraction processes are illustrated in Fig. 4.

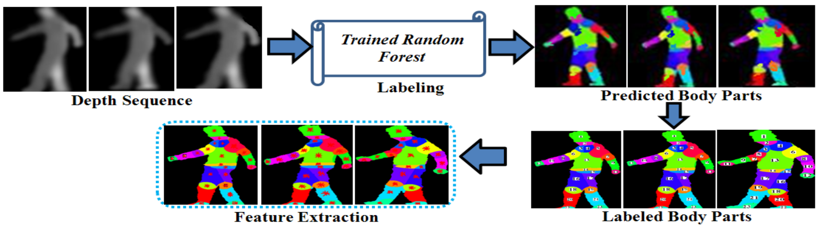


Fig. 4. Overall procedures of body parts labeling and feature extraction

2.3 Activity Recognition via HMM

To perform HAR, we train HMMs [2]. In training, the Linde, Buzo, and Gray [2] clustering algorithm is used to generate a codebook of features from the motion parameters [2] with a codebook size of 32. In our implementation, we used four-state left-to-right HMMs to encode sequential events of the features. Finally, the trained HMMs are used to recognize activities. Fig. 5 shows an exemplary HMM of a right hand waving activity before and after training [2].

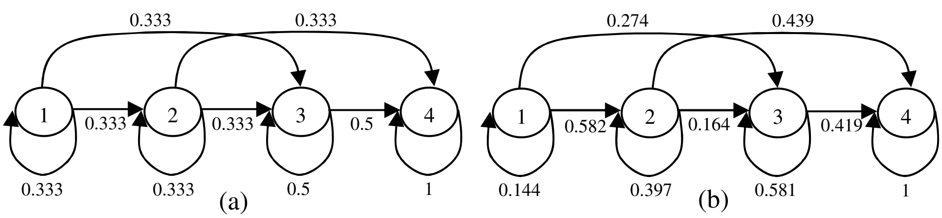


Fig. 5. A right hand waving HMM (a) before and (b) after training

3 Experimental Results

In this study, we utilized a PrimeSense camera [5] to acquire a sequence of depth silhouettes (i.e., 10 frames in a clip) of six human activities. In our HAR experiments, a set of 10 video clips was used in training and a set of 25 video clips for testing. Table 1 shows the HAR results with our proposed HAR technique along with the results from a conventional HAR method [2], in which the principle component (PC) features of the depth silhouettes after linear discriminant analysis (LDA) and HMMs are used. The superior recognition rates of all activities were obtained with the mean recognition rate of 97.16% whereas the conventional only achieved 79.50%.

Table 1. Recognition results using a conventional method and our proposed labeled body parts based HAR

Activities	LDA on PC features [2]		Labeled body Parts features	
	Recognition Rate (%)	Mean	Recognition Rate (%)	Mean
Walking	84.0	79.50%	98.50	97.16%
Running	78.50		95.0	
Right Hand Waving	85.50		97.50	
Both Hand Waving	89.0		100	
Sitting-Down	72.50		98.0	
Standing-Up	67.50		94.0	

4 Conclusions

In this paper, we have presented a novel labeled body parts based HAR system using depth silhouettes. Our proposed HAR system utilizes motion features from the centroids of the labeled body parts and HMMs for activity recognition. Our experimental results have shown some promising performance achieving the mean recognition rate of 97.16%. The proposed methodology should be applicable to smart homes for better and much advanced HAR.

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The Role of ICT in a Healthcare Moving from "Clinical-Centric" to "Patient-Centric"

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Abstract. We are facing significant changes in healthcare; it is moving from a "clinical-centric" to a "patient-centric" approach where the citizen is motivated and empowered to manage his own health. Its role is extending from treatment to prevention and to remote patient monitoring.This evolution of healthcare is attracting the attention of the industry and ICT will play an important role in this new scenario. Unfortunately there are various challenges and restraints; in this paper we report some of these barriers and propose some guidelines for a successful introduction of new e-health services and for the effective exploitation of personal and at home healthcare solutions.

Keywords: Personal Healthcare, PHC, person-centric, prevention, e-health, telemedicine.

1 Introduction

Major trends are impacting healthcare such as the access to healthcare for a larger number of people, the growing demand for better quality of care, the dramatic changes in demographics (ageing population in Europe), larger number of patients with age-specific, chronic and degenerative diseases and as a consequence skyrocketing healthcare costs[1] and finally shortfall of care staff. To cope with these challenges major changes are needed in the delivery and management of healthcare in order to get improvements in efficiency and effectiveness. Healthcare needs to focus on prevention and to move from a clinical-centred to a person-centred approach. We expect an evolution over the next decade towards a continuous and pervasive care at home and away. In this approach informal caregivers (relatives, friends, volunteers) will play an important role by complementing the tasks of the medical professionals and the patient himself will get motivation and empowerment to better manage his own health through healthier lifestyle, adherence to the prescribed therapy and better medical education.

2 The Role of ICT in the Changing Healthcare

New technologies and mainly ICT will play an important role and will be determinant for this "revolution" in healthcare. ICT will complete the realization of the "digital

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[1] Healthcare spending is expected to grow from 9% of gross domestic product (GDP) to 16% by 2020 in the OECD countries [1].

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hospital" by facilitating and enabling the clinician's work at the point of care (security, decision support, increased productivity, mobile access to information, reduction of errors, cost reduction). Moreover ICT will have a challenging and great opportunity in reshaping the healthcare beyond the hospital's environment by making possible the "home care" and the "personal healthcare". ICT has the potential of making possible the move to a person-centric healthcare. Better leveraging of the potential provided by ICT represents a challenge and at the same time an economic opportunity. Nevertheless it has become evident that market forces alone have been insufficient to ensure the realization of this potential.

3 E-health, a Market still in Its Nascent Phase

According to a recent report the home telehealth market in Europe is very fragmented and – although a considerable range of promising services and systems has emerged from research efforts – wider mainstreaming of ICT-enabled solutions with real world service settings has to a large extent yet to occur [2]. Also in North America e-health market is still in its nascent phase and does not yet fully ensure the availability and take up of the necessary ICT-enabled solutions coming out from the Research laboratories. A study [3] realized on behalf of the European Commission gives an overview of the worldwide market situation: no product fully mainstreamed, partially mainstreamed products available in U.S.A, some localized instances in Denmark, Spain, Finland, UK, Germany, Sweden; only pilots and trial activity in Italy, France, Hungary, The Netherlands, Poland and Japan; little or no activity in the other countries. Nevertheless the market potential is huge [4]. The growing number of older adults and the consequent rise of the number of patients suffering from chronic diseases[2] represent a huge opportunity for the e-health devices / solutions / services market. Market participants agree that the e-health market in Europe is set for exponential growth, driven by the need to face health-related challenges and to take full advantage of innovative technologies flooding the market. It is also believed that the e-health market has the potential to be the third largest in the health sector with a global turnover of Euro 50 to Euro 60 billion, of which Europe represents one third [5], [6].

3.1 Market Drivers and Restraints

We could identify several market drivers for the e-health market (ageing population and growth of chronic diseases requiring continuous monitoring, technological advance, demand for early hospital discharge, shortfall of medical resources, long waiting lists and demand for a personalized healthcare). From the other side heavy barriers still exist and several of them are not related to technology: the lack of coordinated policies at national level and at an European level, the lack of a clear reimbursement policy, the market fragmentation with local market participants and

[2] According to a WHO report (2010) 25% to 60% of older people suffer from chronic diseases such as heart disease, diabetes and COPD.

the difficulties in reaching a market globalization driving cost reduction, the lack of a clear medical, regulatory and legal framework, the lack in some countries of suitable infrastructures and high initial set up costs; the difficulty in implementing joint public-private initiatives and finally the poor integration of Personal Healthcare Systems into the hospital workflow (often related to technical issues but also to reluctance by physicians).

4 New Approaches Needed – Some Suggestions

New approaches are needed to establish the enabling conditions for a successful deployment and exploitation of e-health in Europe and for its integration into the clinical workflow. The move to a "personal healthcare" is changing and widening the stakeholders scenario. The synergic effort of all of them towards a common objective (a better quality of care with sustainable costs) is needed.

The reluctance of the medical community to accept the entrance in the medical world of new technologies such as ICT is often a "cultural matter", a mindset problem. To avoid this barrier, telemedicine should definitely be used as a tool by health professionals and should definitely be at the service of the patients. It should not change the way clinicians practice. It has to fit with the existing framework. The use of technology "should be to support medicine not the other way around".

Industrial co-operation and alliance (e.g. licensing by large companies of innovative products developed by smaller companies; common standardization initiatives) are needed. Collaboration is also needed between manufacturers, system integrators and telecom companies; in this regard it will be of high importance to understand the real commitment of the telecom companies to incorporate remote patient monitoring services in their offer to the market.

Focus of the e-health solutions has to be on prevention and to allow the growth of the market and its sustainability all the solutions must be developed with a fast time to market, must be interoperable and easily integrated. A contribution to this "healthcare revolution" could be the focus on reference architectures for person-centric health management and the related subsystems and tools. It will offer opportunities for a sustainable business.

A user-centred design approach must be followed to foster the acceptance of the final users through the unobtrusiveness of the developed solutions, the ease of use and the awareness of the resulting benefits. Moreover the robustness of the measurement approach is needed to increase the trust of the patients.

5 Expected Benefits

In Europe costs related to Congestive Heart Failure (CHF) represent the 3% of the total health expenditure [7] and according to a study of Frost & Sullivan [8] tele-monitoring could increase the success factor of the treatment of patients with heart insufficiency from 59% to 75% and reduce the average cost per patient per annum from 6,397 Euro to 3,065 Euro. An analysis of the European Commission -

Information Society and Media [7] estimated in the range of 1.5 B Euro the cost saving in Germany for early patient discharge possible through telehealth is in the range of 1.5 B Euro.

Data referring to Italy [9] indicate in 150,000 the number of hospitalized older adults with heart failure, in 10 days the average hospitalization and an average cost for each hospitalization day of 320 Euro**.** If – through e-health solutions - we achieve the objective of a 20% reduction in hospitalization days, only in Italy we could save approx. 300 K days of hospitalization with an economic benefit of at least 90 million Euro per year.

6 Conclusions

As evidenced by several analysts the healthcare system is experiencing a critical situation: demand is dramatically growing both in terms of the enlargement of the healthcare users and in terms of higher expectations with regard to the quality of care.

ICT has the great opportunity to foster the transformation of healthcare toward a "patient-centric" focus. Nevertheless several barriers have to be removed and often they are not linked to the shortage of suitable and advanced technologies but – preponderantly – they are related to political, legal and cultural issues. All the stakeholders (medical professionals, policy makers, institutions, patients and their families, the overall community) need to find the way to cooperate in a common effort.

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A Fuzzy-Based Context Modeling and Reasoning Framework for CARA Pervasive Healthcare

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Abstract. Pervasive computing is allowing healthcare to move from care by professionals in hospital to self-care, mobile care, and at-home care. The pervasive healthcare system, *CARA*(Context Aware Real-time Assistant), is designed to provide personalized healthcare services for chronic patients in a timely and appropriate manner by adapting the healthcare technology to fit in with normal activities of the elderly and working practices of the caregivers. This paper presents a fuzzy-logic based context model and a related context-aware reasoning middleware that provides a personalized, flexible and extensible reasoning framework for *CARA*. It provides context-aware data fusion and representation as well as inference mechanisms that support remote patient monitoring and caregiver notification. Noteworthy about the work is the use of fuzzy-logic to deal with the imperfections of the data, and the use of both structure and hierarchy to control the application of rules in the context reasoning system.

Keywords: Pervasive Healthcare, CARA, Fuzzy Logic, Context-aware Reasoning.

1 Introduction

In recent decades, developed countries have experienced an increase of average life-length with a consequent impact of chronic conditions on the population [1]. Pervasive and context-aware applications [2] have been widely recognized as promising solutions for improving quality of life of both patients suffering from chronic conditions and their relatives, as well as for reducing long-term healthcare costs and improving quality of care.

In this paper we present the CARA pervasive healthcare architecture, with the focus on its fuzzy-based context modeling and reasoning framework. The main components of the CARA system are: 1) Wearable Wireless Sensors, 2)Remote Monitoring, 3) Data & Video Review System, 4)Healthcare Reasoning System. In the case of context-aware services, it is really difficult to get an accurate and well defined context which we can classify as 'unambiguous' since the interpretation of sensed data as context is mostly imperfect and ambiguous. To alleviate this problem, a novel approach using fuzzy set theory as a discovery mechanism for contexts is proposed. The objective of this paper is to present a scalable and flexible infrastructure for the delivery, management and deployment of context-aware pervasive healthcare services to independent living elders.

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2 System Overview

An overall architecture of the *CARA pervasive healthcare system* is shown in Figure 1.

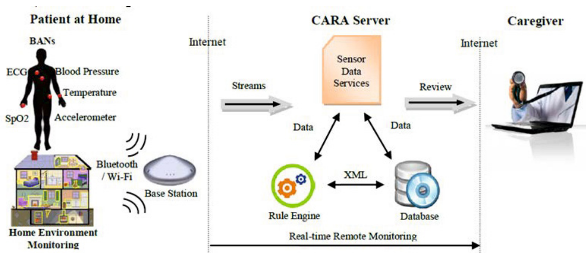


Fig. 1. CARA healthcare architecture

The reasoning engine plays a crucial role in the system both on the gateway and on the server-side as an intelligent agent. It can be tailored with different rules for different applications (such as for in-clinic assessment or at-home monitoring), and it also executes in real-time and offers immediate notification of critical conditions. Some critical conditions may only be identified from correlating different sensor readings and trends in sensor readings accumulated over time. The CARA reasoning component is capable of performing three main reasoning tasks: (i) continuous contextualization of physical state of a person, (ii) prediction of possibly risky situations and (iii) notification of emergency situations indicating a health risk.

3 Context Modeling

Context is any information that can be used to characterize the situation of an entity. And context-aware computing is the use of context to provide relevant information or services to the user [3]. Context modeling is a key feature in context-aware systems to provide context for intelligent services.

The main problem that we consider in this section is the following: given the current raw data, how can we model the context, e.g. the current values of relevant context parameters, and deal with data coming from multiple sources where part of the data might be erroneous or missing. Considering this, we adopt a *Fuzzy Logic Model* to represent the relevant variables and to structure low level and high level context models. All pieces of information gathered by sensors can be indexed as attributes of the context entities. In our work, we represent these attributes as individual *Fuzzy Sets*. Some of the attributes associated with entities in our context model and their fuzzy sets are detailed in Table 1. These fuzzy sets can be used for high level context interpretation and also for decision inference which we will discuss in the next section.

Table 1. Fuzzy sets representing attributes about Person and Area entities

Fuzzy Set	**Attributes**	**Description**
Age	{young, middle-age, old}	Age of the person
Medical History	{hypertension...diabetes}	Has medical history
Temperature	{cold, worm, hot}	Room Temperature
Light	{dark, regular, bright}	Brightness
Sound	{mute, regular, noisy}	Noise level
Location	{bedroom...living room}	Current location

4 Fuzzy-Based Reasoning Engine

We refer to an intelligent monitoring system as a monitoring system that is able to (i) reason about gathered data providing a context-aware interpretation of their meaning and (ii) support understanding and decision. To achieve that in the CARA system, we adopted a rule-based approach based on fuzzy logic for context reasoning.

The interactions in the reasoning engine are presented here. Raw data coming from sensors and associated with context knowledge is processed by the context management services, producing Context Fuzzy Sets. After that, Fuzzy Rules loaded from the inference rule database are used to generate higher level context (e.g., medical condition, activity and accident event). Finally, the rule engine identifies the current state of the patient (normal, abnormal or emergency) based on the combination of high level context. The generated raw data is stored to assist other decisions making and for additional analysis.

The principle of building a fuzzy-based reasoning engine is to design appropriate member functions which are also referred to as fuzzy sets. A membership function is a representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, it defines functional overlap between inputs, and ultimately determines the output response. The fuzzy relations among these fuzzy sets indicate some of the rules in our reasoning engine. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Such rules can be specified by medical experts or a particular healthcare giver. They can also be modified by patient under supervision in case of individualization.

5 Deployment in a Real Application Scenario

We conducted simulation experiments to evaluate the performance of the proposed fuzzy-based reasoning framework in a pervasive healthcare environment and report the results in this section. Figure 2 illustrates the screen shot of our demo application. The monitoring and data review functions are previously developed in CARA system as described in [4]. In this work, we integrated the

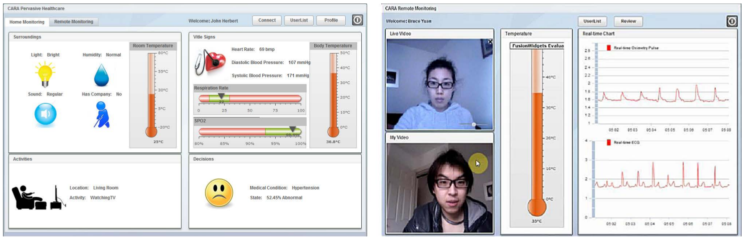
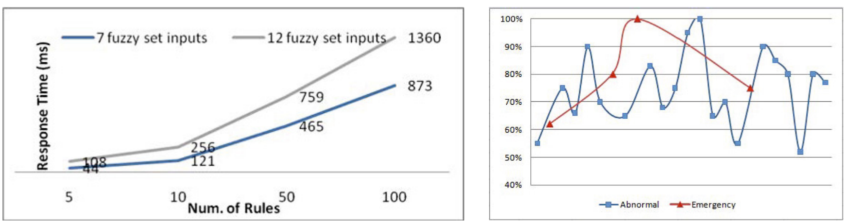


Fig. 2. Snapshot of the CARA pervasive healthcare system. Left is Fuzzy-based context-aware reasoning application. Right is Real-time remote monitoring application.

fuzzy-based reasoning engine into the system which provides real-time intelligence for prediction and prevention in various healthcare situations. To measure the performance of our approach, we added a time check function. We checked a start time before calling the method, and then we also checked a finish time after calling the method. So we can get the execution time of each task. Some of the test results are shown in Figure 3.



(a) Inference performance (b) confidence of prediction

Fig. 3. Use-case testing results a)Different amounts of fuzzy rules are applied and tested with several data sets input. b)The confidence is generated from the crisp output of fuzzy-based rule engine. The confidence value is changed in the range of 52% to 100%.

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A Smart Garment for Older Walkers

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Abstract. Walking is cited as the best form of exercise for persons over the age of 60. In this paper we outline the development and evaluation of a smart garment system that is used to monitor the wellbeing of users in addition to their overall physical activity regimes. A technological solution has been produced offering the desired functionality and is delivered in a simple user-friendly form factor. In this paper we outline the development and evaluation of a prototype as part of an iterative development cycle, with 6 participants aged between 60 and 73 years of age. The results show that technology has the potential to be accepted by older users and improve their activity regimes.

Keywords: Smart Clothing, Activity Monitoring, User-Centered Design.

1 Introduction

The ever increasing trend of population growth, coupled with falling birth rates has resulted in an ever increasing older population [1]. The majority of which exhibit a number of characteristics that are associated with the ageing process, including diminished eyesight and hearing, reduced motor responsiveness and reduced mobility [1]. Within this older population 1 in 3 suffer from 1 or more chronic conditions [2].

The World Health Organization defines health as *"a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity"* [3]. For this reason the work presented within this paper aims to promote and maintain the physical and mental fitness of older walkers in the 60-75 age range. Activities such as walking in later life are seen to significantly reduce the risk of preclinical disability and increase aerobic capacity and physical function [4].

2 Background

As the awareness of the need to maintain a certain level of physical activity increases so too does the number of personal health monitoring devices, which are readily available on the consumer market. Devices such as Nike+ [5] integrate an accelerometer based

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pedometer with the user's iDevice and estimates walking pace, distance, speed and calories burnt. Another system that monitors the activity levels of users is the Garmin Forerunner [6]. It uses GPS (Global Positioning System) to ascertain distance, speed, time and altitude. These two devices cater specifically for younger users and are not designed for use by those with age related characteristics and reduced technological capabilities and hence do not address older user's specific needs. The Design for Ageing Well project [7] aims to address the issue of the autonomy of the 60-75 year old age group using smart clothing and wearable technologies.

3 Methods

A user-centered design methodology has been adopted throughout the development of the system. In the early stages of the project, questionnaires were provided to members of the University of the Third Age [8] to elicit a set of user requirements. These questionnaires asked the users about the current technology they took with them when walking and what their views were regarding its usability. To supplement the results of these questionnaires, two user workshops were organized to obtain further detailed feedback from potential users between the ages of 60-75. Based on the feedback from the questionnaires a set of requirements was established [9], a summary of these requirements is presented in Table 1.

Table 1. Summary of user requirements elicited from questionnaires distributed to older walkers and hikers (>60 years of age), showing the desired functions of walkers only (*N=50)*

Requirement	Walker %
Keep me in contact with my group	54.2
Tell me where my group members are	26.2
Help me navigate	54.8
Call for help should I fall	52.4
Tell me the distance covered already	54.8
Tell me where to find the nearest bus stop	23.8
Tell me where to find the nearest facilities	38.1
Monitor my health for medical reasons	16.7
Interact with my mobile phone	35.7

Once user requirements were established a technology mapping exercise was undertaken to identify the best technologies for each requirement [9]. The elicitation of user requirements and the technology mapping exercise formed the basis for the development of the prototype system. The prototype consisted of an Android Smartphone, Shimmer [10] sensor mote, Sony Ericsson LiveView [11] and an Adidas sports base layer with integrated textile electrodes. The Smartphone acted as the main hub to which peripheral devices would connect via Bluetooth and it would also store and process the data collected by the Shimmer mote. The Shimmer mote is a small wearable sensor that can, in this instance, collect ECG and accelerometer data. The LiveView device is a small micro-display that connects via Bluetooth to the Smartphone and can be used to display data or activate functions on the Smartphone itself. A simplified UI (User Interface) was developed introducing additional feedback mechanisms, such as the aforementioned micro-display. Figure 1 presents the main technology components of the prototype that is to be evaluated and the application UI.

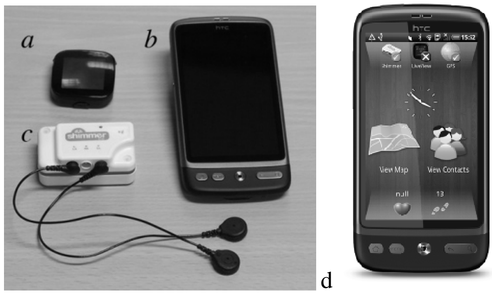

Fig. 1. Prototype components used in the evaluations. a) LiveView micro-display, b) Smartphone and c) Shimmer sensor mote, d) User Interface of the Smartphone application.

Using the Shimmer's ECG and accelerometer data allowed us to obtain the user's heart rate, using a Pan Tomkins algorithm [12], in addition to the levels of activity undertaken. The Smartphone's GPS capability was harnessed to record and transmit the user's GPS location to a central server that allows the viewing of relative location and distance to their friends. By using accelerometer data and the Smartphone's telephony functions a fall detector function was created. In the event of a fall the Smartphone would initialise a call, set the phone to hands-free mode and adjust the volume to the maximum.

4 Evaluation

The user evaluation consisted of 6 participants (*Male = 3, Female = 3*) between the ages of 62-73. All participants used the prototype during a short outdoor walk (15-20 minutes) in order to ascertain functional, aesthetic and UI feedback.

Male participants were asked to wear a modified Adidas based layer, 2 of the 3 female participants wore Textronics chest straps, and 1 female participant wore a custom designed bra, all of which included textile electrodes.

Following a brief overview of the system functionality, all participants were asked to undertake the walking activity in order to evaluate the system. Following evaluation of the system participants were asked to complete a post-evaluation questionnaire which considered factors ranging from the technology they currently have, to the overall usability and functionality of the developed system. It should be stressed that the evaluation did not aim to evaluate the effectiveness of the textile electrodes, step count, fall detection accuracy or the garments.

All participants, as part of the post-evaluation questionnaire, were asked if they liked using the system. Three participants answered *'Yes'*, 2 answered *'No'* and 1 answered *'Yes & No'*. From comments added by the participants, it seems most of the dissatisfaction with the system came from unreliability and slight inaccuracy of measurements i.e. Step count. Three of the 6 participants thought that the current system improved their walking experience with one remarking *'Potentially'*. This particular user clarified this statement by explaining that the system was difficult to use but if simplified they could envisage using it. A further two stated it would not improve their experience. The participants, in general, thought that the system was easy to use, with 2 participants stating the system was *'Easy'* to use and 3 stating that the system was *'OK'* to use, with one stating *'Very Difficult'*.

5 Conclusions

The aim of this evaluation was to ascertain the usability of the developed prototype with particular focus on the UI and core functionality i.e. recording a user's walk. Based on the feedback received, the system was on the whole viewed as beneficial to the participants with 3 participants believing that the technology could enhance their walking experience. Five of the 6 participants, in general, thought the system was easy to use, with answers ranging from *'Easy'* to *'OK'* to a question on usability. Feedback from this evaluation will be taken on board and the prototype will be redeveloped for further evaluation before finally going through a final development stage. Following this the entire system, including the complete clothing system, will be evaluated over a period of 4 weeks within the user's own environment.

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Indoor Location Tracking Based on a Discrete Event Model

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Abstract. Some Ambient Assisted Living approaches are based on location tracking of the inhabitant. In this paper special finite automata are introduced to describe the dynamic indoor tracking process. A method to systematically generate the automaton is presented only using the topology and the sensor instrumentation of the house. Based on the discrete event model of the automaton an algorithm for location tracking has been developed. To clarify the foregoing an illustrative example is used throughout the paper.

Keywords: Ambient Assisted Living, Discrete Event System, Finite Automata, Location Tracking.

1 Introduction

The increasing of life expectancy leads to new issues concerning the autonomy and the independence of elderly or disabled people. To cope with this important society problem, numerous Ambient Assisted Living (AAL) approaches are developed.

Some recent works are dedicated to the location tracking of one or more inhabitants. One of the basic techniques consists in determining if the inhabitant is at home or if the house is empty. Such an home occupancy approach, based for example on the monitoring of the power consumption and the ambient light, is presented in [1]. More accurate location tracking approaches aim to get the exact location of the inhabitant within his house. For instance, two approaches [2,3] are considering houses equipped with binary sensors (motion detectors, switches...). In [2], the knowledge of the real-time location of the inhabitant is aimed to improve the quality of the detection of health problems. In [3], the current location is tracked and the future location is predicted in order to optimize the energy consumption of the house. Despite a common location tracking objective, different models are used in the two approaches. Two graphs (one representing the connectivity of zones and another representing the connectivity of the sensors) are used in [3] whereas a Finite State Machine is taken as a model of the house in [2]. Nevertheless, in both cases the building of the model is only based on the knowledge of an expert. No methodology is proposed for a

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systematic construction of this model starting from the topology and from the instrumentation of the house. In both approaches, the possible inaccuracy of the location is envisaged but the causes of this uncertainty and its relation to the chosen instrumentation are not examined. Furthermore, neither the relationship between the model and the signals emitted by the sensors installed in the house nor the location tracking algorithm are clearly defined.

In this paper, a new approach for systematic generation of a Finite Automaton (FA) describing the motion of a single inhabitant in his home is proposed. This method is aimed to be the most generic and to be compliant with any home and any instrumentation with binary sensors only. This approach is described in the next section. The application of this approach on a case study is given in section 3. Finally, a conclusion and an outlook for future works are given.

2 Overview of the Proposed Approach

In the case the instrumentation of a house is performed using binary sensors only, the tenant moving in the house can be observed through signal events emitted by the sensors. The problem of location tracking of an inhabitant can then be considered as a Discrete Event System (DES) modeling problem. An appropriate way to model such a behavior is to use Finite Automata (FA). A FA is a quadruplet $\langle Q, \Sigma, T, Q_0 \rangle$ with Q a set of states, Σ a set of input events, $T \subseteq Q \times \Sigma \times Q$ a transition relation between states, labeled with input events, $Q_0 \subseteq Q$ a set of initial states.

An overview of the proposed approach for the systematic construction of a FA, representing the possible motion of an inhabitant into a house (or an apartment) equipped with binary sensors and its use for tracking the location of the inhabitant is given in Fig. 1.

In a first step, the topology of the apartment has to be described using a matrix-based formalism representing the topological links between the different rooms of the apartment. A *Topology Graph* is then systematically generated ①. For each room of the house, a node is created and for each direct path between two rooms, an edge between the two corresponding nodes is defined. For a given apartment, it is assumed that only one topology can be described, and thus only one Topology Graph can be generated.

In a second step, one or several possible instrumentations of the apartment with binary sensors have to be described. For each of these instrumentations, matrices representing the detectability area of each sensor are written. Knowing the Topology Graph previously built, a second algorithm allows the systematic generation of a *Detectable Motion Automaton* (DMA) ②. Each transition of the DMA representing a path between two rooms is associated to the events of sensors that can be observed when the inhabitant is moving between the rooms.

In a third step, the relevance of each of the possible instrumentations (in terms of ability to detect the movements of the inhabitant and precision of its location) can be evaluated by analyzing the DMA. This evaluation leads to the validation of a given instrumentation or to the choice of the best one among several possible instrumentations ③. The algorithm consists in choosing the instrumentation minimizing the number of undetectable and inaccurately detectable changes of location of the inhabitant.

Finally, real time location of the inhabitant and its tracking during his movements into the apartment can be performed for the chosen DMA ④. The current state S of DMA represents the location of the inhabitant and S is updated according to the observed events.

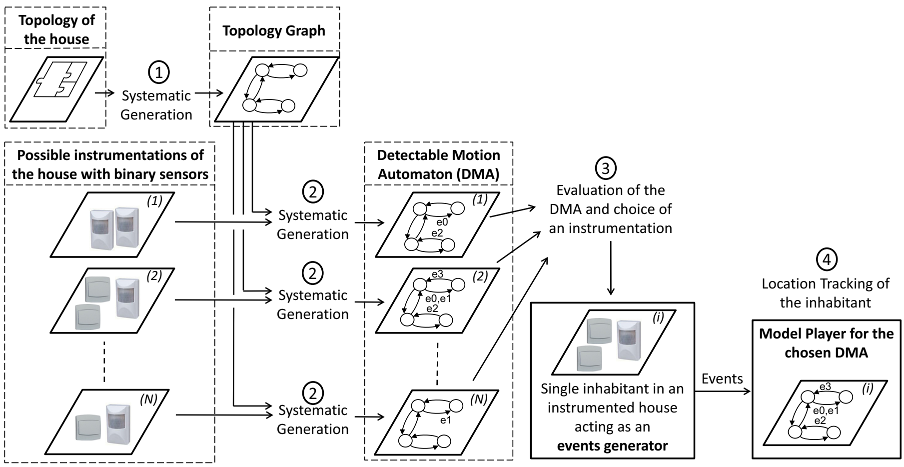


Fig. 1. Global view of the proposed approach

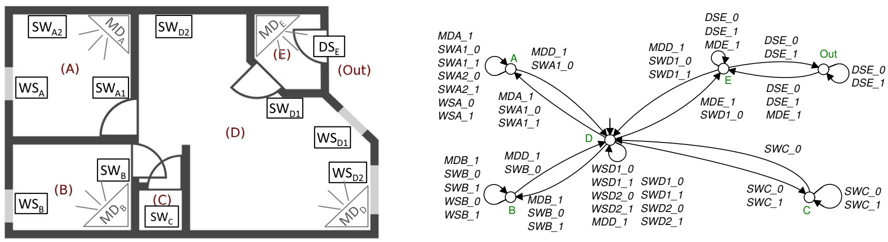
3 A Case Study

This approach has been applied to a real house with people living inside. The topology and the current instrumentation of the chosen house are shown in Fig. 2 (a). It is composed of 5 rooms (a bedroom A, a bathroom B, a closet C, a living room D and a vestibule E) and Out. Different types of binary sensors such as Switches (e.g. SW_{A1}), Windows Sensors (e.g. WS_B), Door Sensors (e.g. DS_E) and Motion Detectors (e.g. MD_D) are installed in the different rooms.

Based on the formalization of the topology and the instrumentation using vectors and matrices, the DMA is generated. It is shown in Fig. 2 (b).

To define the initial state of DMA, a simple method is to install the user interface in a particular room (in our case in the living room D). Each time the monitor is initialized by the inhabitant, it is known that he is in this specific room and then the location tracking algorithm is correctly initialized.

Experimental results have shown that location tracking using this model performs well under two conditions. There has to be only one inhabitant in the house and no other one nor a pet. It is also assumed that no fault of any sensor occur. Future work will be devoted to relax these two hypotheses.



(a) Topology and instrumentation (b) Detectable Motion Automaton

Fig. 2. Application on a case study

4 Conclusion and Future Work

In this paper, a method aiming to systematically build a model of any instrumented home has been introduced. It was tested in a real environment and showed promising results.

The use of FA is proposed because this is a standard formalism in the field of DES. Many developments have been introduced to deal with more sophisticated behaviors. For instance, a timed behavior can be modeled using timed automata or the uncertainty can be taken into account using stochastic automata.

Future work on this topic will be devoted to the location tracking coping with multiple inhabitants. Some promising results have been presented in [4] but the DES theory could be of particular interest to deal with this issue. Another challenge is to use the proposed FA with an algorithm of sensor fault detection and isolation. These methods are devoted to manufacturing systems but it seems that they can be adapted to AAL issues.

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Smart CDSS for Smart Homes

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Abstract. Smart Home is an emerging area of healthcare applications. Various candidates' healthcare applications have been developed to monitor patients at their home environment. Recent developments show that most of the applications provide some conventional guidelines and reminders to patients regarding medications and related physical activities. In this paper, we proposed a novel approach of Smart CDSS that actively provides expert guidelines to patients from approved knowledge of clinicians at their home environment.

1 Introduction

With emerging technologies on hand, people are striving to facilitate the life with smart living standards. Smart Home is one of the resulting paradigm of these emerging smart technologies. The future smart homes are envisioned to be equipped with autonomic services that facilitate life from various perspectives. The most prominent services are related to healthcare. For example, in smart home environment, many decision making services are deployed to monitor activities of person. Daily monitoring of health condition is in high demand at home care to prevent diseases effecting lifestyle [1]. Based on health condition monitored for chronic diseases, the demand for formal clinical guidelines is increasing to provide patient with suggestions and recommendations that help them to manage lifestyle accordingly. Most of the above mentioned reminder systems in smart home only provide reminders and guidelines based on daily activities. In this paper, we propose Smart CDSS (Smart Clinical Decision Support System) service that provides approved guidelines and recommendations of clinician to patient in smart home environment. We have already designed and populated the knowledge base for diabetes based on HL7 Arden Syntax.

2 Smart Home Applications Layered Architecture

Keeping in view complexity of smart home applications and business workflows, smart home application can be designed into four layers. The analysis of each layer in terms of business processes to be modeled with the layered architecture addressed by [2]. At Hardware Layer variety of sensors are deployed that interact

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with sensor applications to provide information of activities.Home Communication Network (HCN) support services for various networks including ZigBee, Wi-fi and blue-tooth.Autonomous Decision Making layer (ADM) incorporate minimal decision services and coordinate the structure data to service layer. Service layer resides services that are directly available to smart home stakeholders. Smart CDSS is an example that will provide guidelines and reminders to patient under care in smart home.

3 Smart CDSS Service: Design and Architecture

Smart CDSS is standard base service that provides guidelines and reminders to smart home applications. The Fig. 1 depicts overall architecture of Smart CDSS service with all intended modules.

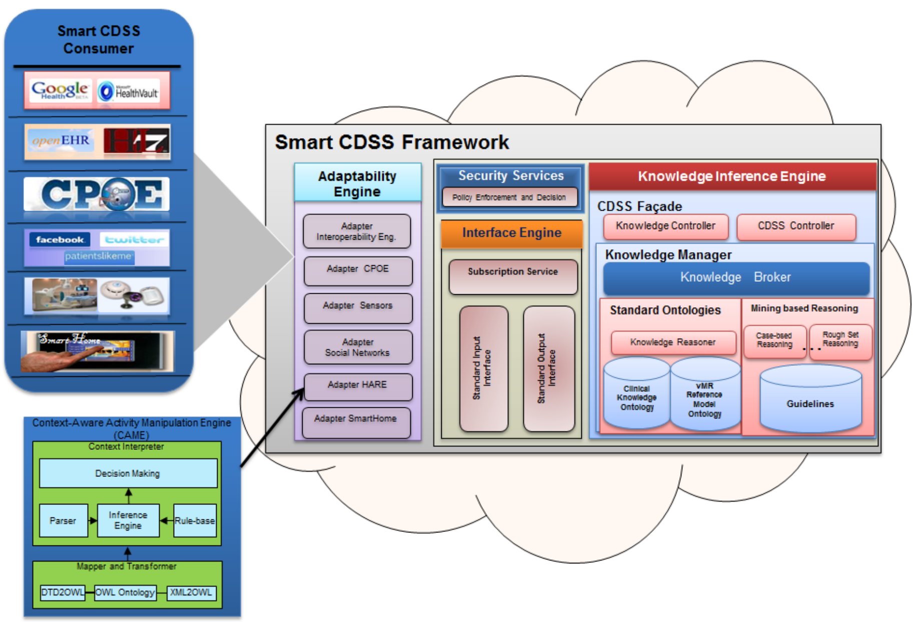

Fig. 1. Smart CDSS Architecture

Knowledge Inference Engine (KIE) include Clinical Knowledge (CK) ontologies based on HL7 Arden Syntax [3] and HL7 vMR standards [4]. The CK is represented in standard ontology where reasoning occur using SWRL (Semantic Web Rule Language). **Interface Engine (IE)**defines vMR standard input and output interfaces to ensure seamless integration of various application to Smart CDSS. **Adaptability Engine (AE)** allow to transform complex heterogeneous application input into standard base Smart CDSS input and output to application specific format.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<activities>
    <activity type="Motion">
        <detectedBy>Motion Sensor</detectedBy>
        <hasName>Mr J</hasName>
        <activityName>Leaving Bedroom</activityName>
        <id>1</id>
        <time>2011:05:16:01:00:00</time>
    </activity>
    ........................
    <activity type="Medicine">
        ..........
    </activity>
    ........................
</activities>
```

Fig. 2. Diabetic Patient Activities under Observation

4 Smart Home Adapter Design for Smart CDSS

Smart Home Adapter (SHA) is playing pivotal role in integration with Smart CDSS services. The SHA module resides at service level of layered architecture, and transform smart home activities of interest of diabetic patient to standard clinical statement and vice versa.

4.1 Structured Information at Smart Home Activities

The partial information shown in Fig. 2 collected through application discussed in [5] , for various activities for Alzheimer patient can equally be applied for diabetic patient. This activity information becomes input to SHA to be converted to standard input for Smart CDSS.

4.2 Standard Smart CDSS Input of Smart Home Activities

Smart CDSS take standard input with patient information and corresponding clinical statements. Clinical statements represent problem, encounter, procedure, goal, supply, substance administration, observation and adverse events. So the diabetic patient activity information shown in Fig. 2, can be represented via problem and substance administration clinical statements mentioned in vMR specifications [4].

5 Conclusion

The paper introduced clinical decision support service for smart home. The proposed solution is based on existing standards like HL7 Arden Syntax and HL7 vMR that enables Smart CDSS as semi plug and play service for various applications. The structured input of diabetic patient has been modeled into standard input specified by HL7 vMR standard that is used as reference input by Smart CDSS. Using Smart CDSS at smart home environment, we can extend solution for various diseases particularly for monitoring and managing elderly peoples.

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Context Awareness for a Smart Environment Utilizing Context Maps and Dempster-Shafer Theory

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Abstract. In this paper we describe context awareness for a smart home using previously collected qualitative data. Based on this, context experts estimate to what extent a behavior is likely to occur in the given situation. The experts' estimations are then combined using Dempster-Shafer Theory. The result can be used to (a) predict the most likely behavior and (b) to verify to what extent a behavior that has been detected is usual in the given situation.

Keywords: Smart Homes, Context Awareness, Dempster-Shafer Theory.

1 Motivation

Instead of moving to a care giving facility, many elderly or cognitively impaired people prefer to stay in the comfort of their own home, which in many cases even has a positive effect on their ability to fulfill the activities of daily living [1]. To aid the person whenever necessary a smart home system firstly must recognize what its inhabitant is currently doing, often based on sensor readings e.g. [2-5]. Once the behavior is identified the question arises: To what degree is the behavior normal or abnormal with respect to the context of the situation, e.g. the weather being nice, her blood sugar level being low, etc?

In this paper we describe how Dempster-Shafer Theory (DST) [6-7] can be utilized to achieve context awareness for a smart home by calculating the degree of normality of a behavior in the context of the situation it appears in.

2 Utilizing Dempster-Shafter Theory for Context Awareness

Generally, what context information needs to be considered depends on the particular inhabitant, it is often manifold, and includes: daily, weekly, and monthly routines, health condition, etc. A *context variable* is a property of the environment that can be measured e.g. day of week, indoor temperature, and weather condition. We opt for an approach where no previous assumption about which context variable influences which behavior has to be made. Instead we collect all context variable values

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whenever a behavior occurs in so called *context maps*. Whenever a behavior takes place, all context maps for that behavior, make an entry in the appropriate field that corresponds to the current value of the context variable. Table 1 shows two context maps for the behavior of grocery shopping. We can, for example, see from the weather map that during the time the inhabitant was observed (in our simulated case we annotated the context for each behavior in 1000 cases) she went grocery shopping 270 times while it was raining, and never while it was snowing.

Table 1. Context maps for the behavior of going out for grocery shopping

GROCERY SHOPPING									
WEATHER MAP					BLOOD SUGAR MAP				
Rainy	Cloudy	Sunny	Foggy	Snowy	Very low	Low	Normal	High	Very high
270	290	310	130	0	0	190	794	0	0

A *context expert* is the part of the smart home system that provides a basic probability assignment (bpa) [6] of its degree of belief to which extent each behavior or behavior combination is likely to occur given the state of the corresponding context variable and the previously collected data in the context maps. For this estimation, the weather expert only takes the context variable weather into account, whereas the blood sugar expert's bpa is solely based on the context variable blood sugar, and similarly for all other experts. Each expert sets the mass for the alternative that describes the most likely behavior or most likely group of behaviors to 1 whereas the mass for all other alternatives are set to 0.

We combine the different experts' bpa with DST [6-7] which has been proven to be useful for behavior recognition e.g. [4]. The specific way of Dempster's rule of combination to deal with highly conflicting evidence is often considered to be negative [9] and other theories have been developed to overcome these issues. One of them is Dezert-Smarandache Theory (DSmT) that also has been used for activity recognition within a home-based care project [5]. However, in our case, we actually profit of Dempster's rule of combination in certain circumstances and will therefore use it in parallel to a different rule, mixing [10], that provides a simple weighted average of the evidence. Both theories together can handle the two different meanings that the basic probability number 0 can stand for (a) the expert can with certainty exclude the behavior (Dempster's rule) and (b) the behavior has never occurred in the given context but there is no reason to generally exclude it (mixing).

3 Results and Future Work

In order to implement and test our approach, we created a scenario of a fictive elderly person, Mary, who lives alone in a smart home [8]. The whole scenario has been simulated by Bayesian networks which create the context data for each behavior. Some of this data is collected in the context maps, as shown above. Other context information that is included in the simulation (e.g. the TV running) is on purpose left out to capture the problem that there are, in reality, more variables influencing an inhabitant's behavior than possibly can be observed in the smart home. To illustrate our results we will use a simple example with the finite domain of behaviors being: Θ = *{dishes, meal, grocery, none},* where *none* describes the case where no other behavior is possible.

After each context expert provided his bpa, Dempster's rule of combination and mixing are used in parallel to each provide an estimate to what degree each of the behaviors can be considered usual in the given context. Because of the way Dempster's rule deals with highly conflicting evidence, where a mass of 0 provided by one expert renders the behavior also in the combined result as abnormal, we can say that Dempster's rule provides its results solely based on information about which behaviors have been observed in the same context before. Mixing, on the contrary, provides information about what behaviors are principally allowed in the given context while still taking previously observed behaviors into account. The experts' bpa and the results of evidence combination for the three behaviors in the context of March, Saturday, 5am, normal blood sugar and sunny weather is shown in table 2.

Table 2. Experts' evidences (m_m m_d, m_h, m_b m_w), combined results for mixing (m_c, Bel_c, Pl_c) and combined results for Dempster's rule of combination (m_{DS}, Bel_{DS}, Pl_{DS}) for a given context

Context: month = March, day = Saturday, hour = 5am, blood sugar = normal, weather = sunny											
	m_m	m_d	m_h	m_b	m_w	m_c	Bel_c	Pl_c	m_{DS}	Bel_{DS}	Pl_{DS}
{*dishes*}	0	0	0	0	0	0	0	0.8	0	0	0
{*meal*}	0	0	0	0	0	0	0	0.8	0	0	0
{*grocery*}	0	0	1	0	0	0.2	0.2	1	1	1	1
{*dishes, meal*}	0	0	0	0	0	0	0	0.8	0	0	0
{*dishes, grocery*}	0	0	0	0	0	0	0.2	1	0	1	1
{*meal, grocery*}	0	0	0	0	0	0	0.2	1	0	1	1
{*dishes, meal ,grocery*}	1	1	0	1	1	0.8	1	1	0	1	1
{*none*}	0	0	0	0	0	0	0	0	0	0	0

For the example calculations above we used a simple and intuitive function for each expert to assign its bpa. Whenever a behavior has been occurred in the context before an expert simply assigns mass = 1 for that behavior or behavior combination. It is, however, not necessary that each expert uses the same function. Expert functions could be customized to the type of information and/or the needs of the inhabitant. No matter what function an expert uses, its results can be translated into a bpa so that DST can be applied for combination and interpretation of the results. It will be interesting to investigate to what degree customized expert functions will improve the overall judgment of a behavior being normal or abnormal.

The usage of the very simple function applied in the example provides promising results. However, we hope to see more fine-tuned results when we will take the relative frequency of a behavior occurring in the context into account. A behavior that appears more frequent than another in the same context should probably be regarded as more usual than the other.

Because Dempster's rule is not scaling very well for huge amounts of data it will also be necessary to test our approach on a bigger scale, preferable with real smart home data to verify to what extent the approach can be used for context awareness in a real smart home environment and in real time.

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Peer Review Meetings of Family Doctors Show Electronic Data Collection Reduces the Variability of Pharmaceutical Prescriptions at the Local Health Authority of Empoli

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Abstract. The awareness of resource spending, with regards to medical prescriptions, is crucial for clinical governance. The variability of behaviour in writing medical prescriptions by doctors is another crucial factor of clinical governance. Both can be addressed and controlled by showing electronic data collection. Peer review meetings, headed by physicians with statistical and epidemiological expertise, led to a statistically significant decrease in variability of drug prescriptions. In the future, we would like to extend peer reviews to include the topics of in-patient hospitalization, appointments with specialists and all other related medical needs, in the attempt to minimize variability amongst medical requests and behaviours.

Keywords: Peer review, medical prescribing, pharmaceutical expenditure, electronic data collection, prescribing variability.

1 Introduction

The Local Health Authority of Empoli is located in the middle of the Arno River valley and between three main cities of Tuscany: Florence, Pisa and Siena. Each of these three cities has its own university. This Authority includes 15 municipalities of which Empoli is the largest with almost 50,000 inhabitants.

Table 1 shows some data and characteristics of this Local Health Authority.

Pharmaceutical prescriptions, specialist visits or any other health needs and/or requests (eg. assistants, hospital admissions, etc.) consume a lot of resources from the community. All medical needs can be charged to both the family doctor, such as a general practitioner, and a specialist. Only genuine understanding of the values and quantities of prescriptions and requests will generate new awareness in health care spending. Often, doctors do not know how many resources are being used to fulfil all of these needs and requests. It is important that each doctor is shown his individual performance rating and expenditure during the peer review meetings. After a peer review meeting, each physician also has individual access to his performance information on a network website. He may also see his last performance in comparison to the average performances of his colleagues.

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Table 1. Data to December 31, 2010. Per capita pharmaceutical expenditure is the lowest in the Tuscan Region.

Total population	235,864
People > 65 years old	21.7 %
Foreigners	8.5 %
Area	933.30 sq km
Hospital beds for inpatients	491
Hospital beds per 1,000 inhabitants	2,0 (Italy 3,8)
Per capita age adjusted pharmaceutical expenditure	149.50 € (160 Tuscany Region)
N° General Practitioners	178
N° Family Pediatricians	31
N° Physicians who work overnight and holidays	46
N° Anesthesiologists	21
N° Cardiologists	24
N° General Surgeons	18
N° Internal Medicine	23
N° Orthopedics	19
N° Gynecologists	17
N° Emergency Room Physicians	22

2 Materials and Methods

The Local Health Authority of Empoli, Italy has got over 230,000 inhabitants and 178 general practitioners. Over 70% of health expenditures outside of the hospital are due to the health needs and requests being fulfilled by general practitioners. We organized all the electronic data into reports for each general practitioner. We chose general practitioners over other healthcare providers, because they are the group of physicians who control the majority of healthcare expenditure. We focused on pharmaceutical expenditure, because it is more relevant and easier to report and control.

General practitioners were divided into seventeen groups, representing the different areas of the health authority. Each grouping of general practitioners worked in the same territory. Each team elected a general practitioner as their leader and representative at meetings for the health authority. In the past twelve years, we organized peer review meetings every four months to discuss pharmaceutical variability with the aim to make it more like the average value. We therefore calculated the mean of pharmaceutical expenditure and standard deviation for each year from 1999 to 2010. Before each meeting we calculated the data to be shown for peer review. All of the meetings were conducted by a physician who was experienced in dealing with public health, and could utilize the relevant computer software to compile statistics. We compared the average of pharmaceutical expenditure in 1999, including standard deviation, to the average expenditure of the year 2010, taking into account the trends over the years. It is for this reason that we chose *t student* and ‘p’ for the statistical analysis.

3 Results

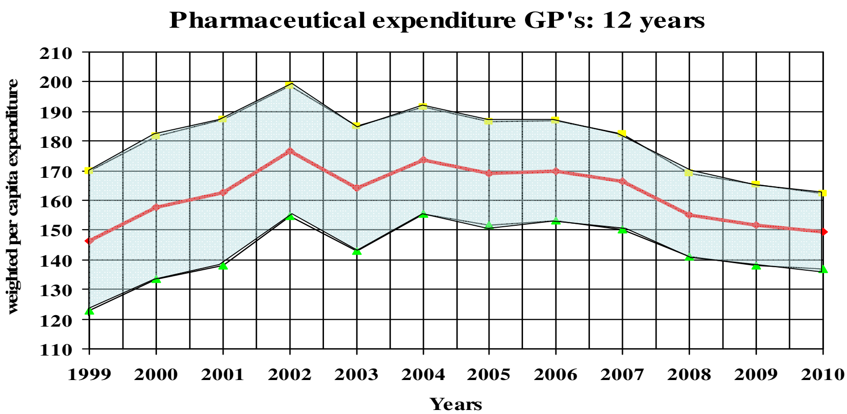
The per capita, age-adjusted, pharmaceutical expenditure increased a bit every year: from an average of €146.29 (value transformed from Italian Liras into Euros) in 1999 to a value of €149.50 in 2010. The standard deviation decreased from €23.55 in 1999 to €12.69 in 2010. This shows that while the per capita expenditure was increasing overall, the gaps of the statistical variability of prescriptions (standard deviation) were decreasing. ($P < 0.01$).

The trend is shown in Fig. 1.

There were no overall adverse effects to the health of patients.

Many general practitioners have reduced their prescription variability, making their behaviour more consistent. These new attitudes evolved during the time of peer reviews where physicians were allowed to comment on and discuss the data produced using SAS statistical software.

These meetings were held three to four times a year, usually between 13.00 and 15.00 in the afternoon. They collected signatures for attendance and were encouraged to attend with small annual attendance fees.



1999=€ 146,29 ± 23,55 St. Dev.

2010=€ 149,5 ± 12,69 St. Dev.

p<0.01

Fig. 1. Per capita, age adjusted, pharmaceutical expenditure from 1999 to 2010, Local Health Authority of Empoli, Italy

4 Conclusions

Frequent meetings with the method of peer review have shown to be able to reduce the variability in pharmaceutical prescriptions of general practitioners with statistical significance. Our continued efforts will include:

- extending electronic data collection, reports and meetings to examine other health needs and medical requests such as hospital admission, specialist requests and other exams, including clinical blood analysis, ultrasounds, resonances, cardiology visits, etc.
- expanding the network site where each physician (not only general practitioners) can see their performances and compare themselves to the average of the Local Health authority, their group, etc.

All these actions aim at raising awareness in order to decrease variability and improve the appropriateness of spending to provide overall savings.

5 Discussion

The comparison and analysis of data carried out among peers is a good way to control pharmaceutical expenditure and other variables of clinical governance.

However, it is very hard to organize frequent meetings between doctors as each meeting must be organised and coordinated. This requires considerable statistical expertise and also communication within the medical field.

Communicative aspects are very important; not only in peer review meetings, but also in daily practice, when the general practitioner and the other doctors face patients with specific health needs, and have to decide which medication or diagnostic procedure is most appropriate. They may also have to decide whether hospitalization is necessary. We intend to continue down this relatively slow and arduous path in order to achieve tangible results.

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Heart Failure Artificial Intelligence-Based Computer Aided Diagnosis Telecare System

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Abstract. In this paper we present an Artificial Intelligence-based Computer Aided Diagnosis system designed to assist the clinical decision of non-specialist staff in the analysis of Heart Failure patients. The system computes the patient's pathological condition and highlights possible aggravations. The system is based on three functional parts: Diagnosis (severity assessing), Prognosis, and Follow-up management. Four Artificial Intelligence-based techniques are used and compared in diagnosis function: a Neural Network, a Support Vector Machine, a Decision Tree and a Fuzzy Expert System whose rules are produced by a Genetic Algorithm. In order to offer a complete HF analysis dashboard, state of the art algorithms are implemented to support a score-based prognosis function. The patient's Follow-up is used to refine the diagnosis by adding Heart Failure type information and to detect any worsening of patient's clinical status. In the Results section we compared the accuracy of the different implemented techniques.

Keywords: Heart Failure, Expert System, Fuzzy Logic, Telecare, SVM, Neural Network, Genetic Algorithm.

1 Introduction

The Computer Aided Diagnosis (CAD) system presented in this paper manages clinical information of patients with Heart Failure (HF). Its purpose is to help the clinical decision of non-specialist staff such as General Practitioner (GP) or Nurses. The system receives as input anamnestic and instrumental data and provides diagnosis and prognosis outputs related to the patient current state also performing a comparison with respect to the patient's clinical history. As a consequence of its functioning, the system builds a database of HF patients providing a valuable core of exploitable knowledge. While anamnestic data is manually entered by the operator the instrumental input data can be also automatically acquired by connecting the system to a

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multi-parametric device for the automatic detection of the instrumental parameters needed for the CAD operation. Hence the integrated system could function as a complete kit for remote monitoring of HF patients enabling also the possibility of telemedicine. With the proposed CAD, patients may be directly assisted by nurses and specific alarms directed to specialist medical staff will be triggered only in case of severe HF diagnosis, patient's aggravation or persistence of critical state.

2 Previous Works

The CAD design is grounded on the comparison and integration of some among the most used technologies in the field of HF diagnosis also establishing which is the most accurate with our patients. Below are brief notes on state of the art of Artificial Intelligence techniques for HF diagnosis. Elfadil et al. classified HF patients in four groups by using Neural Networks (NN) (83.65% Accuracy) [1]. Gharehchopoghi et al. used NN to detect presence or absence of HF obtaining a 85% Accuracy [2]. Guiqiu Yang et al. combined two Support Vector Machines (SVM) to classify HF patients in three groups (74.4% Global Accuracy) [3]. Akinyokun et al. used a neuro-fuzzy system to classify HF patients in three categories (Mild HF, Moderate HF and Severe HF) [4]. Chiarugi et al. implemented an HF CAD that analyzed electro- and echocardiograms. The rules are input in the knowledge base using guidelines and experts' interviews [5]. Candelieri et al. developed a decision tree to detect patient's destabilizations [6] (88% Accuracy). Pecchia et al. used decision tree techniques to classify patients in three groups of severity using Heart Rate Variability measurements. (HF vs Healthy: 96% Accuracy - Severe vs Moderate: 79.3% Accuracy) [7]. The following are the four most important HF score-based prognosis models: *the Seattle Heart Failure Model (SHFM)* [8]; *CHARM* [9]; *EFFECT* [10]; *ADHERE* [11].

3 System Design

Our system is made by three main blocks: Diagnosis (HF severity assessing), Prognosis and follow-up management (Chronological Comparison) as shown in Fig. 1. About Diagnosis block we adopted some proven AI techniques (Neural Network, Support Vector Machine, Decision Tree and Fuzzy Expert System), trained with our database and integrated into a single diagnostic dashboard. As for the Fuzzy Expert System, the rules will be found using a genetic algorithm (Pittsburgh approach). This method has never been used before in the field of HF. The output of Diagnosis block is a three level estimate of patient's current status: Mild HF, Moderate HF, Severe HF. About the score-based Prognosis part, we integrate in a single platform four state of the art main models listed in section Previous Works. The output of this block is a percentage of survival in the next 1, 2, 3, 4 years. The follow-up management consists in a chronological comparison of patient's current status with previous patient's clinical condition saved in the database. This block provides a diagnosis refine in terms of HF type (chronic stable HF, acute episode, etc.) and detects any worsening. Hence the procedure performed by the system depends on the fact that the patient is already known (and so a chronological comparison of patient's status is possible) or is a new patient; in this case only a basic diagnosis is performed.

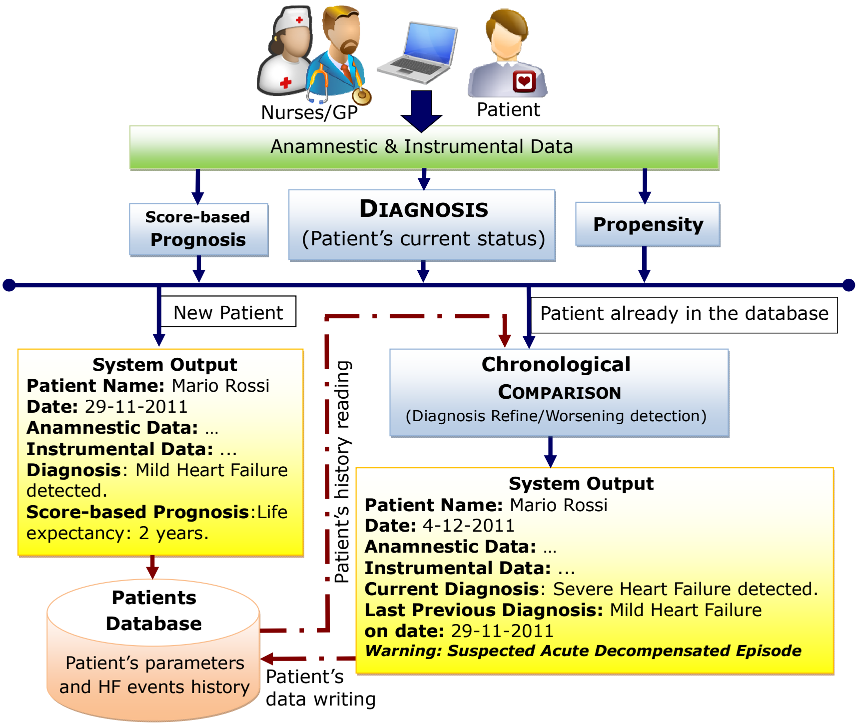

Fig. 1. Schematic Overview of System Operation

4 Results

Currently the CAD is implemented as a prototype. Below the structure of our dataset (Tab.1) and preliminary results of the Diagnosis block are shown.

Table 1. Dataset structure

Training - Test Set	N° of Mild HF patients	N° of Moderate HF patients	N° of Severe HF patients	Total
Training Set	35	31	34	100
Test Set	15	8	13	36

Best results in classifying patients in Mild HF, Moderate HF, Severe HF groups are obtained with the NN that correctly reclassifies 98 out of 100 Training Set patients also maintaining a good generalization ability as it correctly classifies 31 out of 36 Test Set patients (86.1% Accuracy). Other results are summarized in Tab. 2.

Table 2. Performances of classification techniques

AI Technique	N° of correctly classified patients		Total Accuracy in classifying Test Set patients
	Training Set (100)	Test Set (36)	
Neural Network	98	31	86.1%
SVM	74	25	69.4%
Fuzzy - Genetic	74	26	72.2%
Decision Tree	84	28	77.8%

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Benchmarking Results of Semantic Reasoners Applied to an Ambient Assisted Living Environment*

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Abstract. Ambient Assisted Living (AAL) environments and applications have been receiving a great amount of interest in recent years. The main reason of this interest is the increasing lifetime of elderly people. Our goal is to determine and clarify which combination of semantic reasoners and frameworks is the most suitable for building knowledge-driven smart environments. In particular, we are interested in the combination which provides a better computational performance and reasonable memory requirements. The obtained results show that the fastest choice under the employed dataset is to use the OWL API accessing the Pellet reasoner. On the other hand, the less memory consumption experiment is provided by a combination of HermiT and custom Java rules.

1 Introduction

A key component of an intelligent environment is how the user behavior is modeled and reasoned over time in order to assist the user in his activities of daily living. There are several ways to achieve this goal, ranging from statistics to logics and rule-based engines. Generally speaking, there are two broad different approaches for building an intelligent environment or activity recognition system. On the one hand, the *data driven* approach focuses on inferring the activities from the acquired data without using any a priori knowledge model, that is, without explicit knowledge. On the other hand, the *knowledge driven* approach relies on logic based methods. Well-known Description Logics (DL) provides high expressiveness and when combined with appropriate computational properties are the underlying theory for ontologies. The main drawbacks of this approach are: (i) it requires a priori knowledge engineering task about the world model representation; (ii) their difficulty in handling uncertainty due to the violation of some properties that produce undecidable logics [5].

In this work, we focus on the knowledge driven approach, therefore an AAL environment is modeled using ontologies and different semantic reasoners are applied to a simulated stereotypical scenario obtaining corresponding benchmarking results. The aim of this work is to determine and clarify which combination of reasoners and framework is the most suitable for building knowledge-driven smart environments. In

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particular, we are interested in the combination which provides the best computational performance and reasonable memory requirements.

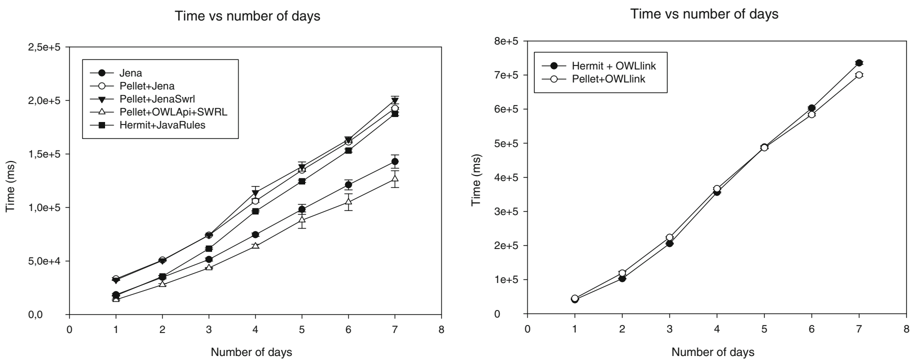

Fig. 1. Obtained results of reasoners execution time as we increase the number of days. Several reasoning tasks are performed every day. The left graph shows the results of the reasoners used as libraries whereas the one on the right side shows the results of OWLlink protocol access to reasoners (Client/Server approach).

2 Benchmark Experiments and Obtained Results

An scenario using the seven days user activities dataset [3] has been employed. In this scenario, an elderly person, who needs help to remember when he must take his medicines, has been modeled.

A core and extension OWL 2 DL ontology have been developed and are the same for all the experiments. In addition to the ontologies, a set of rules has been created. These rules check if the user has taken the corresponding medicament, and advises him when he forgets to take it or when he takes the wrong one. These rules do not try to cover all the possible situations that can be produced, but do at least, the most important cases. Rules have been implemented using SWRL rules and Jena rules format. As rules execution are only available out-of-the-box in Pellet and Jena reasoners, custom Java rules have been developed for HermiT and reasoners used them via OWLlink protocol. These Java rules aim to provide the same inference results as SWRL and Jena rules. The experiments have been carried out using an Acer Aspire 4830TG laptop whose main features are an Intel Core i5-2410M and 8 GB of RAM. The operating system is an Ubuntu 11.10 for 64 bits, using Java 1.6.0_23 version provided by the OpenJDK Runtime Environment. The program firstly loads the ontologies into a reasoner. Then, it reads the simulated activities that the user is supposed to be doing from the dataset and updates the user context. Frameworks and reasoners combinations are summarized in the table 1. Each combination has been executed ten times and the data presented below shows the average and the standard deviation. Figure 1 shows the time needed by the reasoners whereas figure 2 the memory consumption.

As figure 1 shows the fastest choice is to use the OWL API to access to the Pellet reasoner. This result is pretty meaningful, because this approach is a 12% better than

Table 1. Different combinations of reasoners and semantic frameworks used in the benchmark experiments and the kind of rules employed

	OWLlINK API 1.2.2 [4]	*OWL API 3.1.0* [1]	*Jena 2.6.4* [2]
Jena 2.6.4 [2]	-	-	(1) Jena rules
HermiT 1.3.5 [6]	(2) Java rules	(3) Java rules	-
Pellet 2.3.0 [7]	(4) Java rules	(5) SWRL rules	(6) Jena and (7) SWRL rules

the second fastest configuration. However, the fastest configuration has also the biggest memory consumption, as figure 2 shows. In general, these figures do not show a relationship between the necessary time to perform a task and the memory consumption. Another important issue to remark is that in general the reasoner used in combination with the Jena framework (Pellet+Jena, Pellet+JenaSwrl in figure 1 left) is slower than others. However the time performance is improved when the reasoner provided by Jena is employed (Jena in figure 1). This issue could be the result of a more lightweight reasoning support for OWL in Jena reasoners.

We also measure the amount of used memory for the different combination. Memory used includes the memory occupied by all objects including both reachable and unreachable objects. The used memory results (see figure 2 left) show that the best memory consumption combination is to use HermiT+JavaRules through OWL API (case 3 of table 1). In the particular case of Pellet+OWLApi+SWRL (case 5 of table 1) we can notice a inverse relation between the memory consumption and the execution time, since it has the smallest execution time and the highest memory consumption.

In the case of using the OWLlink protocol to access reasoners capabilities, a high increment of execution time is noticed (see figure 1 right). This is because of the required marshalling/un-marshalling of the data and the added abstraction layer. The obtained

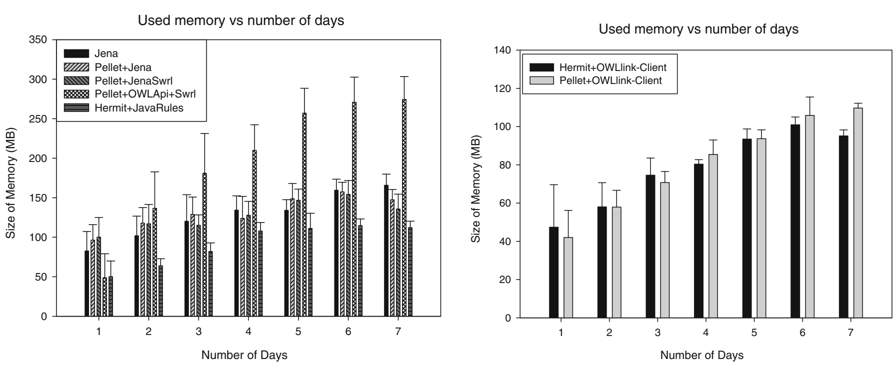

Fig. 2. Used memory results when we increase the number of days. Several reasoning tasks are performed every day. Memory used includes the memory occupied by all objects including both reachable and unreachable objects. The left graph shows the results of the reasoners libraries whereas the one on the right side shows the results of OWLlink protocol access to reasoners (Client side memory).

results of memory consumption shows an equal amount of memory required in the client side (see figure 2 right) as we expected.

3 Conclusions and Future Work

In this work we have measured the performance of several semantic reasoners combined with semantic frameworks in a simulated AAL scenario. The results show that the performance of a reasoner can vary meaningfully depending on the semantic framework used. Regarding memory consumption, we have noticed that the combination of HermiT and Java Rules (see Figure 2 left) provides the best memory consumption. On the other hand, Pellet+OWLApi+SRWL provide the worst one. We suppose that this effect is due to the fact that Pellet implementation needs to transform the internal data from OWLApi format to the internal Pellet representation. In contrast, we suppose that HermiT provides better memory consumption results because it internally employs OWLApi format. An implementation using a distributed architecture might improve the time execution and could be something to be researched. One particular issue that should be considered for AAL scenarios is that OWL 2 does not provide native support to handle uncertainty about the data being modeled. We believe there is a huge room to improve current semantic reasoners through reasoning support under uncertainty and there are few works covering this topic [5].

In the future, we would like to deepen into the particular implementation details of each reasoner/framework combination in order to have more information about the performance and memory consumption differences.

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Medbuddy: A Mobile Medicinal Management System for Children with ADD/ADHD

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Abstract. ADD/ADHD is a chronic, debilitating disorder that can cause patients to be forgetful and disorganized due to the lack of attention. It can be especially disruptive if the patient were a child. Although the exact regimen prescribed is adjusted on a case-to-case basis, the most effective treatment often involves a combination of medicines and behavioral therapies. Medbuddy is a mobile medication management system designed to improve young patients' compliance to the prescription instructions, while attempting to affect positive changes in their behaviors by establishing structured and consistent daily routines and providing both positive and negative feedbacks. By providing timely reminders when it's time to take medications, establishing a reward schedule to reinforce positive behaviors, and interacting with child patients with a configurable avatar, Medbuddy is designed to be an agent of fun that combines medicinal and behavioral treatments to make ADD/ADHD child patients better so they may develop their full potentials.

Keywords: ADD/ADHD, mobile application, behavior reinforce, medication, children, motivation, healthcare.

1 Introduction

ADD/ADHD (Attention Deficit Disorder/Attention-Deficit Hyperactivity Disorder) is a condition that deals with inattentiveness, over-activity, impulsivity, or a combination. Children with ADD/ADHD often suffer from behavioral issues both at home and in school due to their forgetfulness and disorganization. Furthermore, secondary symptoms, such as low self-esteem, aggressiveness and emotional immaturity, can also be observed. From 2003 and 2007, children with ADD/ADHD from age 4 to 17, has increased from 7.8% to 9.5%. The treatment for these children often includes a combination of medications and behavioral treatments. It has been found that behavioral treatment such as alterations in motivational incentives or rewards can have similar effects as medications [1], but with better effectiveness in children [2] and cause much less side effects with comparing to medicinal treatment.

Reisser [3] outlines four techniques when interacting with children with ADD/ADHD: 1.Establish and maintain structure and consistency. 2. Give instructions simply and clearly. 3. Enforce rules and limit consistently and predictably, with

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consequences appropriate for the violation. 4. Offer praise and encouragement. A child with ADD/ADHD needs to know he/she is accepted especially when they often receive more frequent criticism or negative feedback for disruptive behavior.

The aim of medical and behavioral management is to support and allow children with ADD/ADHD to develop their full potentials while keeping the negative effects to the minimum. Taking an active role in the management of their own health not only provide an opportunity to exercise responsibility, but also an encouragement for them to conquer the disorder. A technology that provides medicinal and behavioral management and treatment at all time could greatly benefit these children and their family members.

Medbuddy is a mobile application designed to help children with ADD/ADHD consistently adhering to their medicine regiment by offering simple and clear *reminders* in a timely manner. It introduces stronger incentives, clearer rules and goals by establishing a *reward schedule* to reinforce healthy behaviors and encouraging them to make wise, conscious decisions. Medbuddy keeps both the children and parents *informed on the medication compliance*, so they can work together to manage the ADD/ADHD condition.

The concept behind Medbuddy is inspired by several mobile applications already in existence, but Medbuddy is the first to integrate all of them into one application aims to provide a comprehensive management of medicinal and behavioral treatments of ADD/ADHD. MedCoach [4] is a professional medication management application aims to keep user on track with their medication regimen, with the capability to automatically refilling prescriptions the pharmacy. 'Touch Pets Dogs 2' [5] is a game of electronic pet that allows users to adopt a pet avatar and takes care of it. Reward will be given by taking care of the pet avatar efficiently.

2 System Design and Implementation

System Overview

There are three primary functionalities in Medbuddy: 1. Provide audio-visual reminders through mobile devices, to remind children complying with the medication regimen, while establishing a structured daily routine and taking responsibility for self-care management. 2. Establish a reward schedule, to strengthen the incentives for children to follows through with medication regiment and reinforce positive behaviors. 3. Enable real-time communication between children and parents, so parents can be made aware of non-compliance, enforce the rules when children miss out the scheduled medication. A secondary functionality includes an avatar system that both serves as the primary child user interface and functions as an electronic pet.

Fig. 1. Use cases for parent & child users

Use Cases

As illustrated in Figure 1, parent and child users of Medbuddy have drastically different use cases and requirements. For parent users, the focus is on compliance monitoring and confirmation, as well as administrative tasks of configuring the medicine regimen and reward schedule. For child users, the focus is to support medication intake reporting, reward claiming and interaction with avatars.

Based on the medication regimen setup by the parent, the avatar will deliver the reminder when a dosage is due. The avatar will offer praise and encouragement if the child takes the medicine on time. Otherwise, repetitive reminders will be delivered until they comply, or the parent will be notified after repeated tries. Each compliant medication intake can translate into reward points, to be used for claiming rewards such as activities with friends and parents, gifts, digital rewards, or partaking in special events. Each time the children reports medication intakes, the parent is notified and the corresponding pending reward points appear for the parent's approval. The parent can then send a short message of encouragement along with the approved reward points to reinforce children's positive behaviors. In addition, child users need to take care of their avatar like electronic pets. The avatar needs to be fed, cleaned and entertained regularly, which will encourage the children user to establish and follow regular routines with necessary feedback.

System Design

The fundamental design of Medbuddy follows the traditional server-client architecture, as shown in Figure 2. The server contains a centralize database, authentication and messaging system. Clients are mobile devices consisting of backend, parent and child modules. The communications between the mobile clients and the server are implemented using SOAP/HTTP web services.

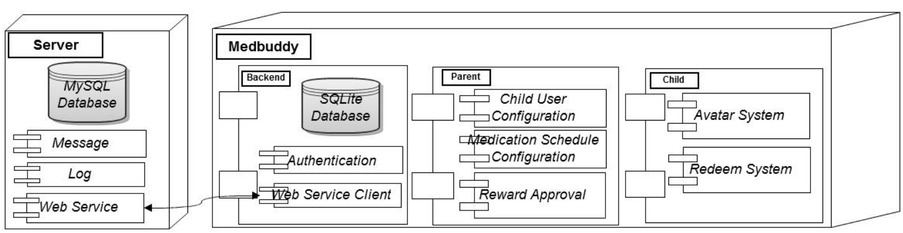

Fig. 2. System Design

The backend module includes a mobile SQLite database and the web service client for communicating with the server and other parent/child devices. There are three considerations when it comes to database: 1. Protects the critical and person medical information; 2. Supports distributed and sequential interactions involving both parent and child users; 3. Functions properly even when disconnected from the Internet. Because of these requirements, the data is stored in a centralized MySQL database on the server, but a mobile light version of database is available to support disconnected mode of operation.

User Interface Design

To accommodate the difference in characteristics and use cases between parent and child users, Medbuddy incorporates two distinct user interfaces (Figure 3).

Parent user interface is designed to be functional and effective, making extensive use of diagrams, tables and charts to deliver the relatively complicated information of medication schedule, reward schedule and medication intake history in a glance. Child user interface is designed to attract and retain users' attention, while delivering friendly and unobtrusive user experience and emotional responses. Using a single avatar with graphical and verbal natural interfaces, we eliminate the clutters and allow children to build rapport with the avatar. The objective is that, by the principle depicted in the media equation, to establish the avatar as a companion to affect positive changes and establish routines and responsibility for the child user.

Implementation

Medbuddy is designed for iOS 5 and implemented using Objective-C to support a wide range of devices including smartphone, tablet and music player. Server modules such as authenticator and user activities logger are implemented with PHP and JavaScript, and the web service for communication are written in Apache Axis2/Java. For databases, we use MySQL for server, and SQLite (a mobile database available in iOS 5) for mobile client.

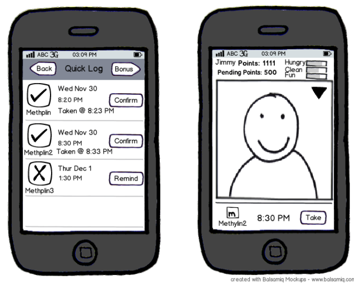

Fig. 3. Parent & Child User Interfaces

Limitation

The current design of Medbuddy is based on honor system, and entirely relies on the child users' reporting, without mechanisms for independent verification on the children's claim. We are currently exploring ideas such as taking photo or video of medication intake, requiring a trusted adult witness to verify the medication intake, or integrate a mobile electronic medication caddy that can automatic report the medication intake events.

3 Conclusion

The number of children suffered from ADD/ADHD has dramatically increased in recent years, and is estimated to affect about 9.5% of all young children. The common consensus is that the most effective treatment requires a combination of behavior and medicinal treatments. Taking advantage on the popularity of the mobile devices among children, an interdisciplinary team of design and HCI students joined force to design Medbuddy. A mobile medicinal management system for children with ADD/ADHD and their parents, Medbuddy not only enable self-management of the medication regimen, but also incorporates features such as reward systems and caring for avatars to encourage positive behaviors and establishes structures and routines.

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An Open Framework for Immersive and Non-immersive Accessibility Simulation for Smart Living Spaces

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Abstract. In this paper, a novel open simulation platform is presented, which aims to provide a virtual prototyping and accessibility testing framework. The proposed framework is based on virtual user models which describe in detail all the physical parameters of a user with or without disabilities. Our approach covers the simulation of all major human functions including motor, vision and hearing through a unified simulation framework. The simulation is carried out in a virtual 3D or 2D representation of the design to be assessed either through an immersive or a non-immersive accessibility evaluation application.

1 Introduction

As global populations are growing older, together with an increase in people with disabilities, the moral and financial need for "designed for All" [1] products and services becomes obvious. Even if there have been some limited and isolated attempts to support accessibility testing of novel products and applications, there is a clear lack of a holistic framework that supports comprehensively virtual user modeling, simulation and testing at all development stages. In [2] the integration of an interactive immersive simulation tool that has been developed in-house with a commercial human modelling simulation system is considered for the planning phase of workplace layouts. SAMMIE [3] is a computer aided human modelling system that represents a widely used tool to accommodate the needs of a broad range of differently sized and shaped people into the design of products. HADRIAN [4] is another computer-based inclusive design tool that has been developed to support designers in their efforts to develop products that meet the needs of a broader range of users.

The present paper presents a framework that performs automatic simulated accessibility evaluation. The great importance of such a framework lies to the fact that it enables the automatic accessibility evaluation of any environment for any user by testing its equivalent virtual environment for the corresponding virtual user. Moreover, the main innovation of the proposed framework lies in the fact that the whole framework is capable of simulating virtual users fully capable or with disablities, having specific motor, vision, hearing, speech and cognitive characteristics.

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2 Simulation Framework

The Simulation Framework consists of four modules: a) the Scene module, b) the Humanoid, c) the Task manager and d) the Simulation module. The Scene module is responsible for the representation of the scene and the management of all the objects in it. The Humanoid represents the human model and controls the humanoid's movements. The Task manager defines the interactions between the humanoid and the scene objects. The Simulation module is the core module of the proposed framework and performs the evaluation process. The general architecture of the framework is depicted in Fig.1.

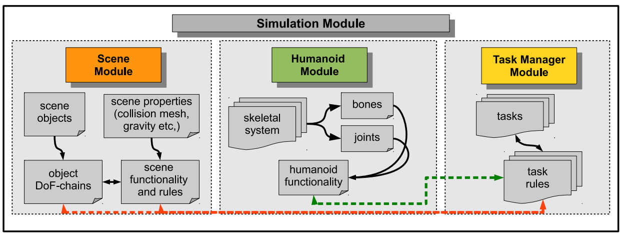

Fig. 1. Overall architecture of the Simulation Framework

The **Scene module** is responsible for creating the scene, managing the objects in it and defining their special attributes. The scene is modeled by two sets of objects: static objects and moveable objects. Both objects have geometry (volume) and visual representation (meshes and textures). Static objects do not have mass and cannot be moved by the humanoid. On the other hand, moveable objects are modeled as rigid bodies, having properties like uniformly distributed mass over their volume (constant density), linear and angular velocity. Complex objects, can be modeled by using a combination of static and moveable objects, and manually defining the degrees of freedom of the moveable parts.

The **Humanoid** is responsible for manipulating the simulated virtual user capabilities. The Humanoid is modeled by a skeletal model that is represented by a set of bones and a set of joints. The bones are modeled by rigid bodies, having properties like mass, volume, position, velocity etc. The joints induce or restrict the movement of their attached bones and have properties such as: a) rotational degrees of freedom, b) minimum and maximum angle per degree of freedom and c) torque specifications as an abstract representation of the muscles attached to the joint. Forward and inverse kinematics and dynamics techniques are supported. Various high level motion planning and collision avoidance techniques are supported by the humanoid module. Configuration space exploring structures, such as rapidly exploring random trees and multi-query planners [5] are used in order to compute a non colliding path for the humanoid. Several vision impairments are supported by the simulation framework and can be used in immersive simulation modes. Spatial and temporal filtering methods are used for simulating the impaired vision. The image filters depend on the vision parameters of the virtual user model and are generated dynamically. A small collection of the simulated vision impairments is shown in Figure 5. Concerning the hearing impairments simulation, the framework supports real time filtering of multi-channel sound, based on the virtual user's audiogram.

The **Task manager** is responsible for managing the actions of the humanoid in order to provide a solution to a given task. After splitting the complex task to a series of primitive tasks, the Task manager instructs the humanoid model to perform a series of specific movements in order to accomplish them. Primitive tasks, like reach, grasp, pull, push, are translated via the Task manager to series of specific motions and are inserted to the humanoid for application. There are several ways of mapping primitive tasks to humanoid movements. For simple tasks such as reach, the usage of inverse kinematic chains produces satisfactory results. For more advanced primitive tasks such as grasp-object, pull-object, specific solvers must be implemented. In order to cope with the complexity of each task, the task manager uses a system of task rules. Each task may have a set of rules that are checked at each timestep.

The **Simulation module** gets as input a Virtual User Model file (that describes a virtual user with disabilities), a simulation model (that describes the functionality of the product/service to be tested) and a virtual 3D environment representing the product/service to be tested. It then simulates the interaction of the virtual user with the virtual environment. Then the specific disabled virtual user is the main "actor" of the physically-based simulation that aims to assess if the virtual user is able to accomplish all necessary actions described in the simulation scenario, taking into account the constraints posed by the disabilities. The simulation module acts also as the supervisor of the other three modules.

3 Applications

Two examples are presented in order to show how the proposed framework can be put into practice (Fig.2. In the first scenario, the telephone usage was simulated for two different designs; one where there is a wall phone at the right of the seated virtual user and a second where the phone is on the desk. The scenario in both designs was described by one task: reaching the phone. Three virtual user models were used: a) user with no disablities, b) an elderly (60 to 84 years old) with reduced range of motion in the upper limbs and c) a user with rheumatoid arthritis that has reduced range of motion in the shoulders. The exact models' specifications can be found in [6]. The simulation results depicted that all virtual users managed to reach the phone in both designs, but in terms of strength and energy, the design where the phone is on the wall is less demanding for all the users. Regarding the comfort, the design where the phone is on the desk seems to be better for the normal user and the user with rheumatoid arthritis, while the elderly user's body postures seem to be more comfortable in the case of the wall phone.

In the second scenario, the avatar is used to evaluate the accessibility of a 2-floor house internal architecture. The scenario task contains the locomotion from the ground floor to the second floor. The Simulation Framework was used in order to provide information about the number of the user's steps, total walking time and possible path finding issues, e.g. due to narrow corridors.

(a) (b) (c)

Fig. 2. Evaluating the phone placement on desk (a) and on wall (b). Evaluating the user locomotion in a 2-floor building (c).

4 Conclusion and Future Work

The present paper proposes a open framework that performs automatic simulated accessibility testing of designs in virtual environments using fully capable and impaired user modelling techniques. The great importance of such a framework lies to the fact that it enables the automatic accessibility evaluation of any environment in a variety of applications. Several features of the simulation framework need further investigation and improvement, such as the speech and cognitive simulation processes. However, even in its current state, the framework provides a valuable design prototype accessibility test tool.

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