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6th International Conferen
Ames, IA, USA, June/July 20
Proceedings

Lecture Notes in Computer Science 5120

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Carl K. Chang Mounir Mokhtari (Eds.)

Smart Homes and Health Telematics

6th International Conference, ICOST 2008
Ames, IA, USA, June 28–July 2, 2008
Proceedings

Springer

Volume Editors

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Library of Congress Control Number: 2008929565

CR Subject Classification (1998): C.2.4, C.3, C.5.3, H.3-5, J.3-5, I.2, K.4, K.6

LNCS Sublibrary: SL 3 – Information Systems and Application, incl. Internet/Web and HCI

ISSN 0302-9743
ISBN-10 3-540-69914-7 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-69914-9 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media

springer.com

Printed in Germany

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India
Printed on acid-free paper SPIN: 12324491 06/3180 5 4 3 2 1 0

Preface

We often conceptualize that older adults retire into a life of carefree luxury among palm trees, golf courses, and pristine beaches. Unfortunately, reality differs today – many retire in place, and often it is the case they retire in rural areas far from hospitals and care-giving centers. For instance, over half of the older population in the state of Minnesota lives in small towns away from the center of care, which is Minneapolis/St. Paul. This year, ICOST 2008 aimed at focusing on this important reality and on gerontechnology—the use of technology to enhance the quality of life of older adults in rural lands.

We had a strong technical program this year spanning many critical topics including: remote monitoring and tele-care, access control and privacy preservation, understanding user requirements and needs, autonomic learning and reasoning about user behavior, activities and contexts, user interface design, middleware for sensing and actuation in smart homes, cognitive assistants, context-aware service provisioning, among other topics.

We received a total of 54 submissions of papers, abstracts and posters, from 14 different countries. Through a blind review process, we accepted 24 full papers, 9 abstracts, and 7 posters. Each submission received two or three reviews with the exception of a few that received four reviews. We are thankful to all the reviewers who helped in the review process including members of the Technical Committee and the additional reviewers that we needed to compensate for unreturned reviews.

We are thankful to the ICOST Scientific Committee members for all the advice and support they provided. Special thanks are extended to Professor Carl Chang for his serving as the General Chair and for his enthusiastic contribution to the entire technical program development process. Thanks also to the ICOST 2008 Local Organization Committee in Iowa for their hard work to make the conference a success. We are very thankful to José Reyes Álamo, for his tremendous efforts in maintaining the conference website and the paper revision system. We also thank all the keynote speakers, panelists, and authors for their contribution to the exciting technical program of ICOST 2008.

We hope you enjoy and benefit from the papers in this volume.

June 2008

Sumi Helal
Johnny Wong
ICOST 2008 Program Co-chairs

Message from the General Chair

I welcome you all to the proceedings of a very special, international gathering. We came together at Iowa State University to continue forging a concerned community to address critical issues pertaining to the wellbeing of our parents, friends, neighbors, physically challenged citizens, and the emerging and fast-graying baby-boomers. For many scientists, engineers, and technologists, it is our collective responsibilities to develop and deploy tested cutting-edge tools and techniques to help people. For health-case professionals, policy makers, and social workers, the conference provides a golden opportunity to have the first-hand experience with what is upcoming on the horizon that will become highly relevant to your profession, and interact and receive technical information from true experts in the field. Oftentimes the audience of smart home technologies happens to be someone who is dear to us. That may help explain why so any researchers are very much passionate about their work. Indeed, the conference theme this year is "Quality of Life Enhancement for People with Special Needs."

ICOST started in 2003 and has gained significant momentum and prestige. We witnessed many prominent researchers and professionals from around the world in this cross-disciplinary research area working together and investing their precious time to make each year's event a great success: Paris (2003), Singapore (2004), Canada (2005), Ireland (2006), and Nara, Japan (2007). This year, we are privileged to be able to host this event in Ames, Iowa, USA. Organizing an international conference entails a lot of work and especially team work. We are fortunate to have a strong team of voluntary and professional workers. I thank each one of them for their outstanding job. In particular, I thank Peter Martin, Mary Yearns, and Jennifer Margrett, who played an integral role in every piece of program development.

I would like to take this opportunity to express special thanks to the following sponsoring and supporting entities. John Brighton, Vice Provost for Research and Economic Development at Iowa State University, provided the leadership to come up with a significant joint grant that made this conference financially viable. David Oliver and Michael Whiteford, who provided partial funding from ISU, deserve my sincere appreciation for their continuous support of the Smart Home initiative at ISU. Karin Ford, representing the Iowa Department of Public Health-Office of Disability and Health, hosted the Welcome Reception in the elegant Christian Petersen Museum. Thanks also to the ICOST 2008 Local Steering Committee from the State of Iowa, who played a critical role in every stage of the planning and publicity.

Finally, Mounir Mokhtari and Tatsuya Yamazaki, and other senior volunteers serving on the Scientific Committee, provided the strong support, encouragement, and shared their experience in organizing this event. Their network helped pulled in many submissions, and, of course, we could not accommodate them all. Sumi Helal and Johnny Wong expertly handled every detail of the technical program development. To them, I owe a lot.

June 2008

Carl K. Chang
General Chair, ICOST 2008

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An Intelligent RFID System for Improving Elderly Daily Life Independent in Indoor Environment

Kung-Ta Huang, Po-Yen Lin, Chih-Yen Chiang, Jui-Sheng Chang, Chih-Ning Huang, and Chia-Tai Chan

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Abstract. Since elderly obliviousness causes social inconvenience and psychical complaint, elders often forget daily schedules and miss their personal belongings such pillboxes or keys. Recently, technological advancements have spurred various ideas and innovations to apply on elder independent living. In this article, we proposed an intelligent RFID (Radio Frequency Identification) system to assist elder living independent and improve aged quality of life.

Keywords: Reminder, elder independent life, self-care, RFID.

1 Introduction

Since the USA population of people over the age of 65 is growing rapidly and is going to reach over 14% of population in 2010 [1]. A growing social problem is supporting older adults who want to live independently in their own homes. Similarly, it has exceeded 10% of Taiwan population in 2007 [2]. Obliviousness is one of the most common problems result in some social inconvenience and psychical complaint. Recently, technological advancements, such as the development and widespread use of wireless LAN (WLAN), ultrasound and RFID (Radio Frequency Identification) have spurred various ideas and innovations to apply on daily living [3]. More accurately, information communication technology (ICT) has the potential to assist elder living independent. In this research, we investigate the role of intelligent agent for the elders to improve successful aged quality of life.

Due to the advantages of passive RFID, power free, cost effective, small volume, and easy attachment to the personal belongings, it is convenient to tracking the objects. If users leave the region and forget the personal belongings, the system will remind them by sending an alarm. The combination of these functions can be used to help elderly individuals to live independently in their own home depending on the individuals' specific requirements. Based on above discussion, we proposed an intelligent RFID system, it consists of multimedia interactive platform, RFID reader, and antennas around the elder that performs schedules reminding and objects tracking.

The reminder system is devoted to improving the convenience of elderly daily life. Reminding function notifies elders what they forget to carry and provides location awareness of some personal belongings. Scheduling function makes elders easily to

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 1–8, 2008.

manage self behaviors and inform them to do something at that time. Some information like doctor's advices and health knowledge can be displayed through the reminder screen according to user requirements. Reminder system is like an intelligent agent not only to bring elders convenience and safe feeling but also to improve elders' self-care behaviors.

The rest of the paper is organized as follows. Section 2 introduces RFID technologies overview. Section 3 describes the design and the features of proposed system. The implementation and the some applications are addressed in section 4. Section 5 concludes the work.

2 Overview

RFID have become increasingly popular to track and identify objects and people. The major features of RFID are readers and tags. Tag is a small object, such as an adhesive sticker, that can be attached to or incorporated into a product. RFID tags are composed of an antenna connected to an electronic chip which transforms the energy of radio-frequency queries from an RFID reader or transceiver to respond by sending back information they encircle [5]. Tags can be divided into passive tag and active tag. Active tags can emit the RF with 2.45GHz ISM frequency through a unique ID to connect the readers, and vice versa. The transmission distance is about 100 feet according to the power of system. Passive tags are typically read with 13.56 MHz at some centimeters of distances, generally deploying in luggage check in airport or indoor location awareness. The advantages of passive tag are power free, light weight, and size small that can be easily attached to personal belongings, basically fitting the deployment requirements in the resident environment.

Electric Product Code Generation 2 (EPC GEN2) is a novel advanced RFID technology, as compared with traditional RFID, letting people access and retrieve the tag information with faster data rate, greater security, and specific purpose [9]. It uniquely identifies objects and facilitates tracking throughout the product's life cycle. EPC GEN2 promotes the widespread deployment of RFID and offers a great value for many applications, especially in manufacturing, supply chain management, and object tracking.

Several successful RFID applications have been developed in hospital since it is a promising technology. In order to reduce the medical error of misidentify and improve patient care, administration and productivity, several RFID-based patient identification and pilot tracking projects have been implemented in most hospitals [6]. RFID-tagged wristband also can make the operating theater safer and more efficient due to the relevant information in RFID tag [7]. RFID enables the Unit Dose Distribution Service (UDDS) which is widely adapted for inpatients drug delivering to enhance the precision of medicine delivering and alleviate nurses' works, like "3-read and 5-right" rule [8]. Also, diverse applications for different requirements, such as equipments tracking, blood identification. RFID absolutely becomes a practical technology for healthcare besides industries or manufactories.

As the increasing with rapidly growing elder population, intelligent reminder system plays an important role to support elder independent living [10]. Our research focuses on assisting elders to remind their schedules and objects via EPC GEN2 RFID technology, furthermore, improving their quality of life.

3 Intelligent RFID Reminder System

The primary goal of reminder system is making elder living more convenient. Our reminder system can provide both location tracking and scheduling to help elder resident life. We use passive RFID tag to locate the mobile phone, wallet, key, etc. When elder leaves his house, the RFID reader beside the door will scan all the tags attached to his belongings, and remind him forget to carry something he needs. What is more, reminder also can notify elders what need to do according to their daily schedules.

The deployment of the reminder system in home environment, including RFID readers, passive tags, antennas and multimedia interactive platform, is shown in Fig.1. First, passive tags are attached to personal belongings and the antennas are placed at the entrance of rooms. Once an antenna senses the passive tag, then homecare server will locate objects and remind the elders with message or voice through the multimedia interactive platform. Also, the homecare server records the positions of elders and belongings for classifying the elders' behaviors. Multimedia interactive platform provides the functions of self-configuration and location tracking when elders miss their belongings.

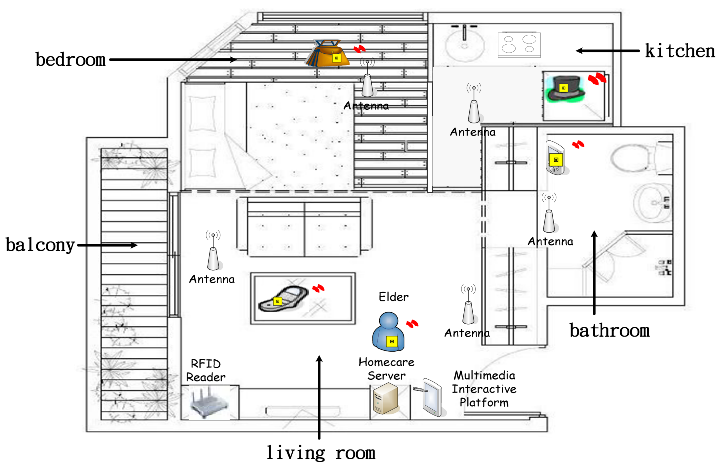

Fig. 1. Intelligent RFID Reminder system

Reminding and scheduling are two main functions of reminder system according to elders' behaviors. As previous description, reminding function will inform elders while they forgot to carry their keys or canes with message or voice. The design is based on event driven, as shown in Fig.(2a). The antenna near the door will periodically sense all the RFID tags attached to the predefined objects and the system will determine which objects elders miss, then remind them. Searching objects option is also a practical requirement that assists elders to find it more quickly. Meanwhile, location history can also provide information for advanced behavior classification.

Elders often need to take medicine on specific time, lock the door and windows, and turn off the gas when they go to bed. Once they forgot, it may cause the serious accident especially for elderly life. The proposed to-do list and e-mail are not suitable solutions. Since elders still forgot to check to-do lists attached to fixed furniture like refrigerator or table and often have no idea using the computer with e-mail. Consequently, scheduling function must fit the requirement for easy setting and accurate reminding. The design principle of scheduling function is time driven as shown in Fig.2(b). First, user can set his schedule on multimedia interactive platform by himself according to his behaviors and date, if the current time conforms to the pre-scheduled time, it will send related message to inform the user what his schedule is.

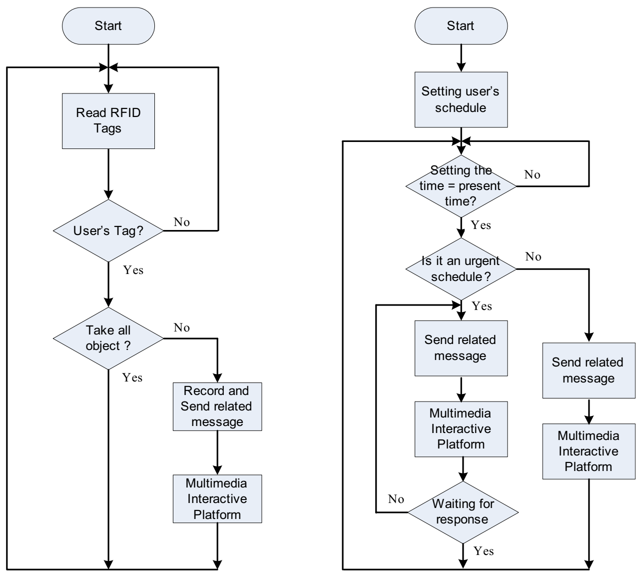

Fig. 2(a). Event driven flow chart **Fig. 2(b).**Time driven flow chart

4 Implementation

In this section, we introduce the architecture of the RFID reminder system. We adopted the centralized design due to cost effective, easy management, faster error recovery and simplifying the device carried by users. Based on EPC GEN2 antenna capacity, reader can successfully sense the objects in our experiment. The effective sensing distance is 1 meter with tags inside the pocket (front), 1.5 meters within bags, and 3 meters exposed in a non-shielded state respectively. Reminder system is developed based on JAVA and Microsoft Access. The detailed description of the system architecture and prototype are presented in the following subsection.

4.1 Reminder System Architecture

The architecture of RFID reminder system can be classified into three layer physical layer, middleware layer, application layer as shown in Fig.3.

- Physical layer is the fundamental layer of the system architecture. It provides the integration of diverse hardware, network and operating system, such as network interface card (NIC), passive RFID reader (EPC GEN2) and tag etc. Information exchanges within above hardware instruments via heterogeneous communication interface.
- Middleware layer is based on JAVA and provides the functions of data access, data control, and computing. We can implement adaptive criterion to determine the function of the application layer and utilize the algorithm to classify the elder habits in order to prevent some accidents. It is flexible to design diverse algorithms on JAVA environment such as genetic algorithm or neural network.

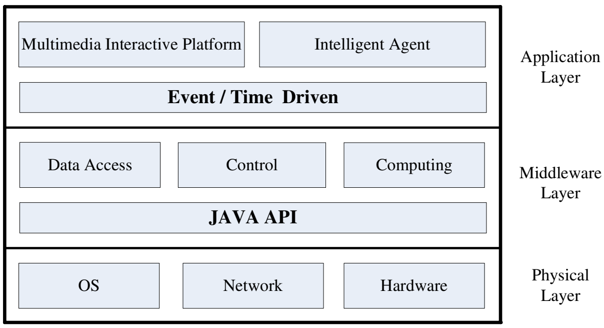

Fig. 3. Reminder system architecture

- There are two parts in application layer: multimedia interactive platform and intelligent agent.
  - Multimedia interactive platform is a device with a widescreen LCD and a touch panel with capabilities let elders to set up their living schedules and search their items. In residential environment, the platform can locate items actively and can be queried where the items are with graphic user interface (GUI). Meanwhile, reminding message will pop out from screen if they miss something when they leave their home.
  - The intelligent agent provides the reminding and scheduling functions.

Forgetting the important things and the daily schedule are happened frequently on the elder people. The following scenario is used to illustrate the availability of the proposed reminder system. Mr. Liu, aged 70, is a diabetic patient who lives in his home with poor memory by himself and needs to control his blood glucose by insulin several times a day. One day he needs to see a doctor, when he passes the front door, the antenna of the front door will scan all the RFID tags attached to personal belongings. Then system will check if the received UIDs match with pre-set UIDs, and remind him of forgetting the wallet with voice alert. Moreover, diabetic patients need to avoid low blood glucose by taking meals or snacks within half hour due to the stronger medicine effect. Low blood glucose will result in stomach fever and disgorge, easily be mistaken to general stomach disease, the worst case will be in coma if the patient forgets to take medicine and snacks. It is worthy to note that reminder system will inform the elders to take medicine at specific time and provide where the medicine is and some healthy information to improve elders' self-care behaviors.

4.2 Reminder System Prototype

We have already implemented the intelligent RFID reminder system. Elders can use friendly GUI to configure the function of the reminder system as shown in Fig.4 and Fig. 5. The GUI functions consist of Reminding, Connection, Location History, Real Time Monitoring, Pre-set Schedule, and Item Searching. The reminding shows the items what elder carries and their UIDs after informing what he misses. Connection displays whether each tag is connected to antennas. Location History exhibits the previous locations of tag. Real time monitoring shows both the unique ID (UID) and location of one specific item, letting elder finds something more quickly. Pre-set Schedule provides user to set the system to remind him on specific time. Item Searching means the system searches a tag in its database and shows where it is when user wants to find an object.

In our experimental environment, there are four RFID antennas deployed around our lab, one is in the meeting room, another is outside and the others are in the lab as shown in Fig.6. Each antenna's coverage is set nearly 5.79 meters long and 3.07 meters wide fitting the size of general space of resident environment. The result reveals that system can recognize what object belongs to which region accurately. By this location awareness of objects, reminder system successfully utters recorded speech sound to remind user who just leaves the lab and misses his notebook.

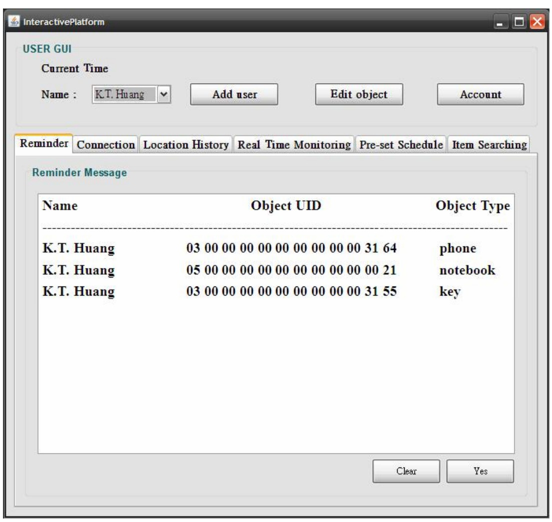

Fig. 4. Reminder interface

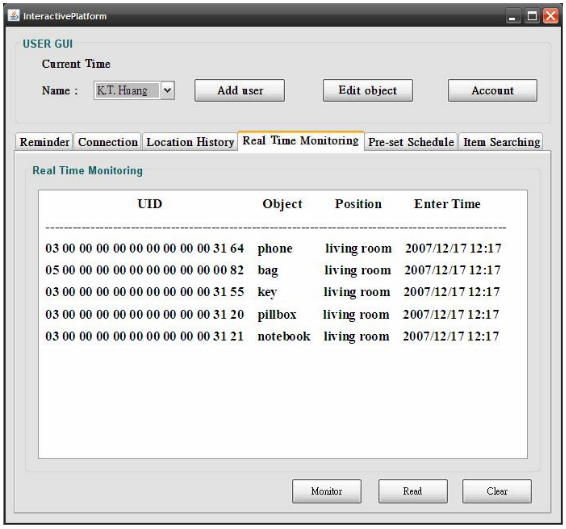

Fig. 5. Real time monitoring interface

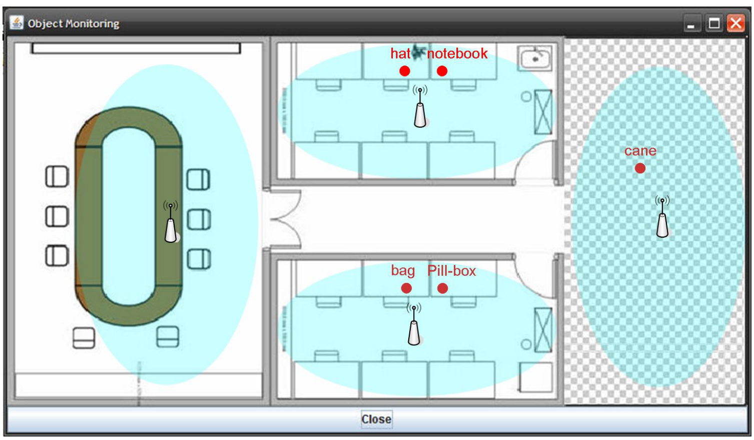

Fig. 6. Location-aware of objects and antennas coverage

5 Conclusion

To improve quality of life for elders, the proposed intelligent system is an alternative solution for oblivious problems. RFID reminder system combines with location tracking and scheduling, leading elders take care themselves. There is no need to be surrounded by caregivers in order to remind elders what they miss or what they need to do, lowering great quantity of social cost. It is obvious that RFID reminder system will bring about the convenience of elder life and enhance the quality of their life.

Our initial function of reminder system provides expedient, and the next step is the expansion of functionality. Elders' safety is another issue need to be deeply concerned.

Reminder system can classify the elder living habit depends on their stay time and frequency by using fuzzy theory and genetic algorithm (GA). Reminder system will estimate whether the elder's behavior is abnormal based on the GA result. Advanced functionality and effect will be reported in future occasions.

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HYCARE: A Hybrid Context-Aware Reminding Framework for Elders with Mild Dementia

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Abstract. Dementia occurs much more frequently in the elders who exhibit impairments of memory, thought and reasoning. In this paper, we present a hybrid context-aware reminding framework intended to help elders with mild dementia improve their level of independence and quality of life. Based on the user study in three different pilot sites, the reminding services are identified and classified into four types according to the nature and urgency. The framework with a novel scheduling mechanism is designed which handles both synchronous time-based and asynchronous event-based reminding services. In order to facilitate the interaction between the caregivers and system, we also provide a simple software tool for caregivers to create and edit the reminding services. Finally, we present some initial implementation results.

Keywords: reminding, context-aware, hybrid scheduler, event-based.

1 Introduction

Dementia is a progressive, disabling, chronic disease affecting 5% of all persons above 65 years old and over 40% of people above 90 [4]. People with a diagnosis of dementia experience progressive cognitive impairments that typically start with memory problems but can encompass thought, speech, perception and reasoning difficulties, which lead to an inability to perform the most basic functional activities such as washing and cooking, and in extreme cases to damages and even loss of life. From social, economic and elder's perspectives, it is of paramount importance to enable the elders with mild dementia to remain in their own homes for longer periods, and to relieve the burden of formal and informal caregivers.

Pervasive computing technologies have been proposed to assist elders suffering from mild dementia to improve their level of independence and quality of life through

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 9–17, 2008.

cognitive reinforcement [9]. Much research has been done on the reminders which aim to prompt the elder for performing daily activities. For example, Autominder [10] adopts a plan-based approach to decide when and how to prompt subjects effectively, it handles the time-based activity plan by solving the disjunctive temporal problem. The approach is limited to time-based reminding plan. Location-based reminders are described in [13,5,1] which have all shown location is a key element for reminding services. However, there is more to context than location when designing various reminding services for elders with mild dementia, for example time and user activities are two important elements of context for reminding. Cybreminder [3] and ComMotion [8] are two examples of context-aware systems which support reminder applications. They attempt to build a context-aware infrastructure and make use of rich context information to support reminding services, but they focus more on when and how to prompt the subjects, without tackling the coordination and execution of different reminding services. Helping elders with mild dementia to perform activities of daily living (ADLs) is a hot research area, the basic idea is to monitor if the subject is stuck in a certain step and the system will inform the elder what and how to do in the next step if needed. So far the research is still limited to assisting certain specific activities such as brushing teeth and washing hands [2][7], systems that can assist a variety of ADLs have not appeared yet. Medication prompting is another hot topic associated with reminding services, a statistical reasoning system is presented in [12] for determining in what circumstance the subject should be prompted for medication, but it doesn't provide a general framework for coordinating different reminding services. The wearable computing research community have also explored various reminding approaches [6,11], their focuses are usually more on how to remind people rather than when to remind them.

If we look at all the previous work on context-aware reminders, they mainly focus on when and how to issue reminding signals to the subjects according to the context, they seldom consider the coordination of different reminders and the situation of the reminding activities interrupted by another event, which are common and crucial in assisting elders with mild dementia. For example, a phone call or going to toilet often interrupt the on-going daily routines but they cannot be predicted in advance. The context-aware reminding framework should handle both the synchronous and asynchronous events correctly.

In this paper, we intend to build a hybrid context-aware reminding framework for elders with mild dementia (HYCARE) which can handle both the synchronous and asynchronous events. In particular, we propose and develop a novel scheduling mechanism that can coordinate various reminding services and remedy the possible conflicts. As part of the European project called "CogKnow", this work starts with the user study at three different pilot sites, the reminding services are then classified into four categories and the context-aware reminding rule set is formulated. In order to facilitate the interaction between the caregivers and system, we provide a simple software tool for caregivers to plan the possible reminding services. In Section 3, the hybrid context-aware reminding framework is presented with details, including the reminder planner, the reminder scheduler and the reminder adaptor. In Section 4, some initial results of CogKnow are briefly described. And finally, the concluding remarks and future directions are given in Section 5.

2 Design of the Context-Aware Reminding Services

2.1 User Studies

In the CogKnow project, we adopted a user-centered design approach and performed user studies at three different sites: Amsterdam (Netherland), Belfast (UK) and Luleå (Sweden). Workshops and interviews with 17 elders were conducted together with their caregivers. Four main areas of cognitive reinforcement have been identified as follows:

- Remembering
- Maintaining social contacts
- Performing daily life activities
- Enhanced feeling of safety

While these four areas cover the different aspects of user needs for living independently, each area is somehow linked to reminding the elders of things like appointments, the name of caller, locating the mobile devices and keys, making phone calls, meal preparation, brushing teeth, recharging devices, closing refrigerators, taking medication, turning off stoves, locking doors when going outside. Therefore, the reminding services are considered as fundamental functions to assist elders with mild dementia for independent living.

To look at the needed reminding services, *watching the favorite TV program* should be time fixed, for example, the news program starts at 7:00pm everyday. The subject will miss part of the program if he/she is prompted later than 7:00pm. *Preparing and having meal* can be scheduled based on time, but the prompting can be delayed a bit if the elder is not “ready”, for instance, if the elder wakes up late or is on the phone. In addition to the time relevant daily activities, there are also cases that depend on events. For example, an elder should be reminded of *bringing the keys* with him/her when *going outside* (if he/she forgets so), he/she should be reminded of *washing hands* after *toileting* (if he/she forgets so). In the former case, the *bringing the keys* service should be prompted and executed before *going outside;* in the latter case, the *washing hands* service can be prompted with a bit delay and even not fully executed if it is interrupted by another urgent event such as phone call.

2.2 Reminding Service Classification

Based on the observation of elder’s daily activities mentioned above, we classify the reminding services into four kinds as follows:

1) Time-based Prompting
    - Time fixed prompting service: The prompting is issued strongly at defined time so that the subject understands the urgency of executing certain activity.
    - Time relevant prompting service: The prompting is relevant to a time, but can be delayed within an acceptable time window.

2) Event-based Prompting

- Event urgent prompting service: The prompting is issued strongly when an urgent predefined event is detected.
- Event relevant prompting service: The prompting is related to other events, but it can be delayed within an acceptable window.

2.3 Context-Aware Prompting Rules

We adopt Event-Condition-Action (ECA) rules to describe context-aware prompting rules. While the event refers to the context info such as time, location, user activity, etc; and the condition tells if certain situation happens, then the corresponding reminding service is activated as action. The ECA rules determine when and what to prompt. The following examples are corresponding to the four kinds of reminders:

- Example of time relevant reminding service: taking medication

$$\mathit{Later}(\text{current time, anchor time}) \wedge \mathit{Earlier}(\text{current time, anchor time+delay window}) \wedge \mathit{LocatedIn}(\text{elder, home}) \wedge \mathit{IsSleeping}(\text{elder,no}) \Rightarrow \text{prompt}$$

- Example of time fixed reminding service: watching favorite TV program

$$\mathit{Matches}(\text{current time, TV program}) \wedge \mathit{LocatedIn}(\text{elder, home}) \Rightarrow \text{prompt}$$

- Example of event urgent reminding service: bringing key

$$\mathit{Detected}(\text{elder, leaving home}) \wedge \mathit{IsBringKey}(\text{elder, no}) \Rightarrow \text{prompt}$$

- Example of event relevant reminding service: washing hands

$$\mathit{IsFinishToileting}(\text{elder, yes}) \wedge \mathit{IsWashhands}(\text{elder,no}) \wedge \mathit{LocatedIn}(\text{elder, home}) \wedge \mathit{IsOnThePhone}(\text{elder,no}) \Rightarrow \text{prompt}$$

2.4 Software Tool

To facilitate the interaction between the caregivers and system, a simple software tool as shown in Fig. 1 is built. Caregivers can use the tool to create and edit the prompting rules.

Fig. 1(a) shows a snapshot of reminding service creation and selection. In this example, brush teeth, turn off stove, turn off gas, take medication and drink water are selected as reminding services for the elder named David on Monday, 02/01/2008. History information buttons are provided for recalling previous records. The Edit button near each selected reminding service allows dynamic construction of an arbitrarily rich situation (context) comprising the associated events and conditions. Fig. 1(b) shows the snapshot of composing the events and conditions for the taking medication reminding service.

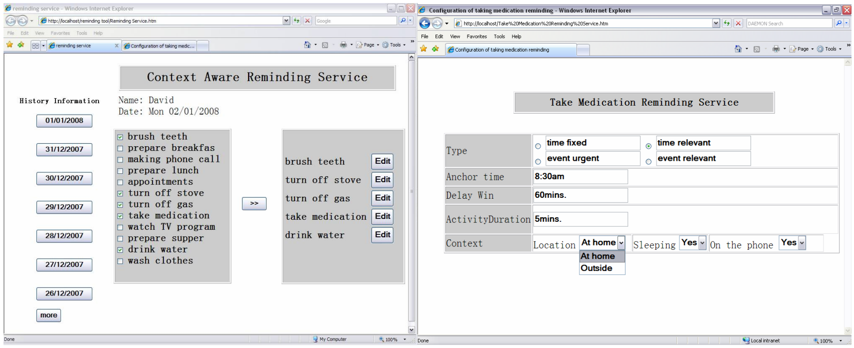


Fig. 1. (a) Software tool for creating and selecting reminding services (b) Software tool for editing events and conditions for Taking Medication Reminding Service

3 The HYCARE Architecture

In this section, we introduce the hybrid context-aware reminding service framework for elders with mild dementia (HYCARE) that supports the processing of those reminding services (as shown in Fig. 2). The core of the HYCARE platform is the reminder processing engine which comprises three components: the reminder planer, the reminder scheduler and the reminder adapter. As the reminding services are context-aware, the acquisition and processing of the relevant context information should be properly managed. The Semantic Space context infrastructure [14] has been adopted to manage the dynamic query and subscription of all the context information related to reminding services.

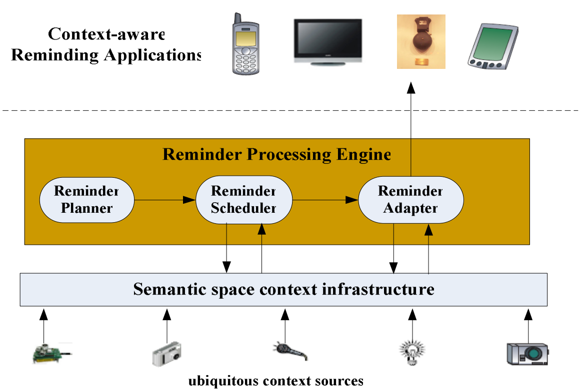


Fig. 2. Context-aware Reminding Service Platform Architecture

The Reminder Planer

Reminding services for elders with mild dementia are different from day to day due to the dynamic nature of people's activities, it is usually the caregiver who plans the reminding services each day, by using the software tool as described in section 2.5. In order to make the planning clear and logic, the reminding services are advised to put into two groups: time-based reminder and event-based reminder. Through sorting the time-based reminding services by *AnchorTime* (the beginning time of a reminding service), the reminder inconsistency can be avoided in the planning stage. The reminder planner is responsible for transforming the caregiver inputs into ECA rules, and mapping the events and conditions in those ECA rules to the appropriate context query and subscriptions for Semantic Space context infrastructure.

The Reminder Scheduler

The role of the reminder scheduler is to schedule all the reminding services planned every day, handle the conflicts during the reminding process, and record if the reminding service finishes properly. In terms of reminding service execution sequence, there are three possibilities:

1. For all the time-based synchronous and event-based asynchronous reminding services, there is no conflict between any two reminders. This is the case when there is no event-based asynchronous reminding service requested, the scheduler just works out a logical sequence for time-based reminding services.
2. When a specific reminding service is triggered and executed, it is interrupted by a more urgent reminding service. For example, when the elder is preparing meal, the turning off gas reminder is triggered.
3. When a specific reminding service is triggered and executed, it is interrupted by an external event which the user chooses to respond. One example is that the elder is interrupted by an asynchronous event, such as a phone call, which causes the reminding service paused. Another example is that the elder totally ignores the reminding service and continues to perform certain activities that are not anticipated by the reminding service at all.

In order to handle the above three cases, a priority-based scheduling mechanism with consideration of reminder timing parameters is proposed as follows:

1. Event urgent reminding services have the highest priority. They should not be delayed nor interrupted by any reminding service with lower priority.
2. Time fixed reminding services have the second priority. They can only be delayed or interrupted by an event urgent reminding service.
3. Time relevant and event relevant reminding services are both in the lowest priority level. For these two kinds of reminding services with the same priority, we use a First Expired First Served (FEFS) algorithm to schedule them.

The basic idea of FEFS is to merge time relevant and event relevant reminding services into one waiting queue. The order in the waiting queue is determined by the *ExpireTime* (the time a service is supposed to expire) of each service. Here we present a simple example to illustrate the idea. In the scenario shown in Fig. 3., there are three time-based reminding services: brush teeth, prepare breakfast and take medication. When it is at 7:30am, the system detects that the elder is in toilet, so the prompting of preparing breakfast is delayed according to its DelayWin (the acceptable delay time window). After the elder finishes toileting at 7:35am, the system finds the elder didn't wash his hands, then the washing hands reminding service is activated and inserted into the FEFS queue. As the *ExpireTime* of the washing hands reminding service is earlier than that of the preparing breakfast service, the washing hands reminding is activated first.

Reminding Service	AnchorTime	DelayWin	ExpireTime	Duration
<1> brush teeth	7:00am	15mins.	7:15am	10mins
<2> wash hands	7:35am	5mins.	7:40am	3mins
<3> prepare breakfast	7:30am	30mins.	8:00am	45mins
<4> take medication	9:00am	60mins.	10:00am	5mins
... ...				

Fig. 3. A snapshot of FEFS queue

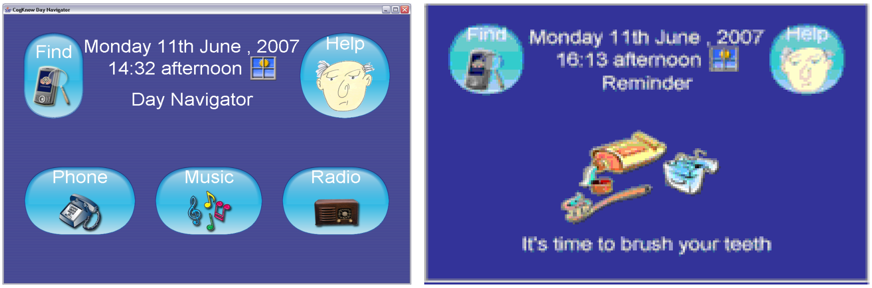
When the more urgent reminding service or external event is complete, whether the system should resume to previous reminding service depends on if the current time exceeds the sum of *ExpireTime* and *Duration* (how long the reminding activity lasts). If it exceeds, the previous reminding service is aborted and recorded as incomplete. In the scheduling process, it is assumed that whether the reminded activity is performed by the subject is known.

The Reminder Adapter

The reminder adaptor determines how to present the reminding message according to the user, device and environment context. Location is a very important context because it is more effective to prompt the elders using the devices nearby, otherwise they may fail to notice the reminding signal. Device constraint is another useful context, while an SMS text message is sent to the elder if he/she stays out of home with mobile phone, a video reminder may be preferable shown in the TV if he happens to watch the TV program at home. Environment context can be also crucial in choosing the right modality to alert the subject, for example, in noisy street vibration is more effective than voice for informing the elders of the reminding message. Due to the length limit of the paper, the detailed design of this module will not be discussed in this paper.

4 System Implementation and Trial

Till now the CogKnow project has already started for almost a year and a half. While the field trial #1 with time and location-based reminders was completed in all three pilot sites, the field trial #2 for context-aware reminding services is planed in April and May 2008. Fig. 4 (a) shows the screen shot for the main menu tested in trial #1, it contains functions such as picture dialing, listening to radio or music, locating the mobile device and making an emergency call. The elders can access those services either on stationary displays mounted on the wall or on the CogKnow mobile device. Reminders are displayed either on stationary display or the CogKnow mobile, depending on the situation. Fig. 4(b) presents the reminder service for brushing teeth.



(a) (b)

Fig. 4. (a)Screen shot for main menu (b)Screen shot for brushing teeth prompting

5 Conclusion

In this paper, we have presented a hybrid context-aware reminding framework for elders with mild dementia called HYCARE, which can handle both synchronous time-based and asynchronous event-based reminding services. In particular, we develop a novel scheduling mechanism that can coordinate various reminding services and remedy the possible conflicts. In order to facilitate the interaction between the caregivers and system, we propose a reminding service description model and provide a simple software tool for caregivers to create and edit the reminding services with respect to the events and conditions.

In next few months, we plan to implement the proposed HYCARE framework with dozens of reminding services and test our prototype in the pilot sites. We believe that the real-world deployment and test are crucial to developing practical and robust solutions for elders with mild dementia. We hope that our novel context-aware reminding framework design and the future trial results will be of particular interest to pervasive healthcare community.

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Evaluation of Mobile and Home Based Cognitive Prosthetics

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Abstract. Those suffering from mild dementia exhibit impairments of memory, thought and reasoning. It has been recognised that the deployment of technological solutions to address such impairments may have a major positive impact on quality of life. In the current paper we present results from the CogKnow Project following the evaluation of a suite of mobile and home based cognitive prosthetics to assist persons suffering from mild dementia. The results following an evaluation of the technology conducted with 16 people with mild dementia (and their carers) across 3 different trial sites are outlined. The paper concludes with details describing the process by which the outcomes of the evaluation will be used to guide the developments of a second generation of both mobile and home based cognitive prosthetic.

Keywords: Assistive technologies, independent living, mild dementia, mobile devices, intelligent environments, evaluation of technology.

1 Introduction

Demographic changes in age, as observed in the last few decades, have resulted in significant efforts being focused towards the research and development of solutions to meet a new set of societal needs and demands. The basic infrastructure which currently supports elderly people, such as homes for the elderly, nursing homes, and other care facilities are becoming insufficient to deal with this increase in the ageing population. In addition, the amount of burden which is being placed on both formal and informal carers is being increased. Furthermore, there is an increasing shortage in the number of professional care providers coupled with a reduction in the number of young family members able to devote time outside of their normal daily lives to

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provide additional support to such persons. Recent efforts have therefore been focused towards establishing a means of 'ageing in place' whereby a technology rich environment can be established to promote levels of independence hence potentially extending the period of time a person can remain within their own home [1].

A specific area of concern within the ageing population who have chosen to remain within their own living environments are the problems associated with dementia. Those suffering from dementia require different levels of support to undertake daily activities due to their impairments in memory, thought and reasoning. In our current work in the CogKnow Project we are aiming to address the unmet needs of people with mild dementia through the introduction of a number of systems and services delivered through the usage of Information and Communication Technologies (ICTs). Through the provision of these new solutions we are attempting to improve upon the autonomy and quality of life of those ageing people with mild dementia therefore increasing their levels of independence. In this paper we will present the evaluation of a cognitive prosthetic and identify how this can be adapted in the future to further support the needs of persons with mild dementia.

2 Background

Dementia is a mental deterioration that affects the brain and exhibits typical symptoms including impairment of memory, thought, perception, speech and reasoning. It may be possible to slow the affect of dementia through prescription medication, nevertheless, as a chronic disease its effects are progressive and irreversible. According to [2] dementia affects 5% of people over 65 and more than 40% of those people over 90. There are approximately 5 million persons with dementia in Europe rising to 18 million at a global scale. Recent estimates have also suggested that the number of people affected is to double every 20 years [3].

Although there have been many efforts in the development of cognitive prosthetics there are relatively few tools, solutions or technologies which have been specifically tailored for the needs of people with dementia [4]. In addition, due to the severity of middle to late stage dementia ICT solutions are not considered feasible within this cohort. As a result, efforts have been solely focused on people with symptoms of mild dementia. In general, ICT solutions being reported have concentrated on providing services to the typical ageing population. Examples include memory aids to help with medication management for those who suffer from memory problems and cognitive impairments, customised mobile phones to facilitate ease of use and promote social awareness [5] and the provision of health care monitoring systems [6]. Nevertheless, there have been some limited studies aimed at introducing services to address the specific needs of people with dementia [4]. Two areas of specific concern for those with mild dementia are safety monitoring and maintaining social contacts [4]. From a safety monitoring perspective, key areas which have been addressed include techniques to assist with wandering both within and outside the home environment. Studies have also shown the benefits of using video phones to maintain social contacts [7]. To assist in developing solutions to address specific issues associated with mild dementia the present work has focused on the identified unmet needs of both the person with dementia and their carer. The present work focuses on the following four areas:

- Remotely configurable reminding functionality
- Communication and interaction functionality
- Supportive technology for performing activities of daily living
- Safety through anomaly detection and emergency contact

In the following Sections we present the methodology adopted to realise cognitive prosthetics for the aforementioned four areas of cognitive reinforcement, we present the system which was developed and finally we present its evaluation following supervised in-situ assessment.

3 Methods

The approach we have adopted within our work has been based on a series of three iterations. Within each iteration user needs are assessed, cognitive prosthetics are developed and, finally, evaluation of solutions following in-situ assessments are performed. The results from each iteration are used to inform the development of ensuing stages. In the following Sections we will describe the approach which has been adopted in the first iteration of this approach.

3.1 User Needs Assessment

A series of workshops and interviews were conducted with people with mild dementia who fell within our inclusion criteria to help define a set of functional requirements to facilitate the initial development in the first phase of the work [8]. To obtain a further insight into the needs of those suffering from dementia workshops and interviews were also conducted for the carers of those with dementia. The workshops involved participation of a group of 17 people with dementia (and their carers) spanning three trial sites throughout Europe (Belfast, Amsterdam and Lulea). Patients were recruited from memory clinics and meeting centres for people with mild dementia. The assessment of the stage of the condition was performed by a qualified clinician based on established clinical measures (refer to [8] for full details). The structure of the workshops across the three trial sites were conducted in accordance with a common protocol. The goal of the workshops, via discussion of needs, wishes and demands of those participating, was to identify the requirements relating to the four areas of investigation which could be used to support technical development. The result of the workshops was a set of documented needs, wishes, and demands which summarised the required services and solutions across the four areas of cognitive reinforcement being focused on in the first version of the cognitive prosthetic. (Full details following assessment of user preferences from the workshops can be accessed in [8] and [9].) As a result, the output of the workshops were subsequently translated into a set of functional requirements (FRs) which were considered as the bridge between the user needs and the technical specifications.

3.2 Technical Development

Based on the FRs a Technical Specification (TS) was established. In realising the TS, four specific components were considered:

1. *Stationary Device*. The stationary device, located at a fixed position within the person's home, consisted of a 17 inch touch screen LCD and concealed processing unit. From a technical perspective, the stationary device is the main hub within the home environment responsible for collecting all information, passing it to the server, and interacting with the other components in the system. Through a graphical user interface the system has the ability to deliver reminder messages, provide a means of social contact through a picture dialling service, support activities of pleasure through support with listening to the radio and pre-stored music and offering enhanced feelings of safety through provision of warnings when doors are left open.

2. *Mobile Device*. To complement the stationary device a mobile component with a small 2.8 inch touch screen display is used to interact with the user. The purpose of the mobile device is to provide a mirror of the services offered by the stationary device which can be accessed from anywhere within the home environment. Furthermore, the mobile component provides the ability to access additional services once the person is outside of the home environment.

3. *Server*: The role of the server is twofold. In the first instance it acts as the information repository for the entire system. In the second instance it provides a means whereby the carer can configure and schedule patient reminding schedules.

4. *Sensorised Environment*. At a general level the sensorised environment supported two low level components, sensors and actuators. For example a door sensor was installed to alert the user if the door was left open and an actuator was used to facilitate remote operation of a manual tuning radio.

All components within the system were integrated via a two part communication model. The first part relied on an underlying TCP/IP network used to transfer XML and Ivybus protocols. The XML facilitated duplex communication between the stationary, mobile devices, and the server. The Ivybus supported the stationary device to access sensor control and data via calls to the sensor network. The second component relied on the power infrastructure cables in the home environment as its primary communications channel using the X10 protocol.

3.3 Evaluation Plan

The evaluation plan established aimed to identify whether or not the mobile and home based cognitive prosthetics met their objectives based on the FRs and the TS. The evaluation process addressed three perspectives: human factors, technical factors and business factors. From the human factors perspective, insight into the user needs was addressed through evaluation of the user-friendliness, usefulness, efficacy and the impact in the previously described 4 areas, on autonomy and quality of life. From the technical factors perspective, evaluation was focused on how the resulting prototype advanced the state-of-the-art. From the business factors perspective the evaluation focused on the viability of the business opportunities, and the identification of critical business success factors. This element of the evaluation will play a larger role in the following two stages of the Project's lifecycle where the formulation of the necessary models to support commercialisation of the system have been planned. The evaluation was planned to be performed following the in-situ assessment of the cognitive prosthetics at each of the three trial sites. In our current work we have focused on the evaluation of the first field test according to our overall methodology and have focused on the human factor and technical factors. The business factor perspectives will be addressed in later field trials. The main research questions were defined in the following areas:

- evaluate basic user friendliness with a focus on hardware-related factors such as form factor, basic interactions, wearability, charging, etc.
- evaluate assumptions about the user friendliness and usefulness of basic concepts used e.g., reminders.
- collect basic data about activities and context in order to inform the design of context-aware features e.g. location detection, activity recognition.

To answer these research questions, a number of methods where applied; pre-test interview, semi-structured interviews along with observational methods. Based on these questions it has been the main intention of the initial iteration of the Project to address the usability and usefulness of the technical Prototype. The second and third iterations of the Project have been planned to support from 3 week to 2 month trial periods for each person with dementia. During these periods it will be possible to collect sufficient data to assess if the technology has an impact in terms of Quality of Life for the user based on how it may compensate for the effects caused by dementia.

4 Results

The evaluation of the system took place during a 4 week period in three locations (Amsterdam, Lulea, Belfast). During each evaluation the system was installed within the person with dementia's home and testing and assessment took place over a period of 0.5-2 days. In total the technology was evaluated with 16 persons with dementia (and their carers). Overall, the evaluation of the first trial showed that the mobile and home based cognitive prosthetics were satisfactory solutions and were easy to use by elderly people with mild dementia. Nevertheless, a number of issues were raised in relation to the levels of user interaction offered by the system along with its lack of ability of attuning to personal situations. A summary of the evaluation in the 4 focus areas from Human Factor and Technical Impact perspectives is presented in Table 1. Table 2 provides details of the evaluation of the 4 key areas for both the person with dementia and their carer for both usefulness and user friendliness. As a result of the evaluation it was found that not only did the results in terms of the usability and user friendliness differ on a site per site basis, the results also differed on a person-per-person basis. To summarise these results in order to provide a meaningful input to the ensuing stage of technical development the features of the system which were deemed of high utility were prioritised at each site. Features which were then to be addressed in the next stages of the process were sought which had high rankings on all three sites.

Table 1. Summary of the Human Factor and Technical impact in the 4 focus areas following in-situ assessment of both the mobile and home based cognitive prosthetic

	Human Factor Impact	Technical Impact
Overall system	*Useful, easy to operate, easy to understand, interaction with touch screen was problematic*	*Problem with sensitivity of touch screen. Server reliable. Experienced stability issues with mobile device.*
Reminding	Reminders were not attuned to personal situations.	N/A
Communication	Picture dialling very useful, however, contained too many steps.	Suffered from lack of reliability of service.
Activity	Value of this service was high. Music was not attuned to personal preferences.	N/A
Safety	Was not fully tested. Is expected to be useful in the future.	The door sensor was not reliable hence caused integration problems.

Table 2. Summary of the Evaluation of the 4 functions for both carer and person with dementia (PwD) for both Usefulness and User friendliness

Evaluation 4 functions	Reminding	Communication Picture dialling	Activity Radio control, music player	Safety Door sensor (limited testing)
Usefulness	-PwD valued use of special event reminders -Carers also valued daily event reminders	-Valued highly by both PwD and carers	-Valued highly by both PwD and carers	-Difficulty relating usefulness to present situation -Future usefulness high
User friendliness	-Audibility good -Size figures on screen good, on mobile too small -Advice: add sound signal to attract attention	-Generally good -Easy to operate and learn how to use -Too many steps -Help function confused with picture dialling	-Generally good -Easy to operate -Icons clear -Music player and radio sometimes interfered with each other and caused confusion	-Easy to understand

5 Discussion

Several recommendations can be made based on the outcomes of the evaluation [10]. Table 3 presents a summary of the recommendations following evaluation from the first field trial. Based on these recommendations the FRs can subsequently be updated and used as the basis for the second field trial. As a result of the aforementioned recommendations a number of interesting design challenges have become apparent. Firstly, it has been identified that there was a need for different forms of personalization. In the first instance this related to the user interface and its colours and size of buttons/fonts. Although customisation of the interface to blend with personal taste is desired, offering many alternatives to persons with dementia may make it difficult to make a selection. In the second instance, the design issues associated with the requirements for the personalisation of the set of services which the cognitive prosthetics offer has become apparent. Persons with dementia have different needs during the progression of the disease. The design issues are then required to address the questions of 'which service should be introduced?', 'what level of functionality should it provide?' and 'when is the appropriate time to introduce the service?'. From the evaluation point of view we have a set of basic functionality that must be used in all field test locations. In practice, this is an important issue to guarantee usability. Some seemingly simple issues such as the location of the stationary device in the home may also influence the usage and efficacy of the device. In Sweden for example people live more in the kitchen, in the UK and Netherlands people spend more time in their living rooms.

Table 3. Summary of recommendations to be incorporated into ensuing versions of the mobile and home based cognitive prosthetics following evaluation of the first Field Trial

	Human Factor	**Technical**
Overall system	*The level of interaction offered by both touch screens within the system should be improved.*	*Levels of stability offered through the touch screen interaction should be improved. Stability of operation of the mobile device should be improved along with streamlining of services offered. Investigate elements of context awareness and personalisation.*
Reminding	Reminders should be more personalised and also should support personal configuration.	Develop facilities to support personal configuration of reminders along with multi-modal interaction.
Communication	Reduce the number of steps required for picture dialling and improve their logical flow.	Simplify the current complexity of operation.
Activity	Requires personal configuration.	N/A
Safety	Requires further development.	Requires deployment of more stable sensor based environment.

6 Conclusion

In our current work we have aimed to address the unmet needs of persons with mild dementia through the development and deployment of mobile and home based cognitive prosthetics. As part of this work we undertook an evaluation of the impact of the system from both a human factor and technical perspective. The system was evaluated following a series of Field Tests performed on 16 persons with mild dementia (and their carers) with each trialling the technology for 0.5-2 days.

The assessment of the evaluation will be used to inform the ensuing cycles of technical developments. Both the human factors and technical factor evaluation provided useful feedback to help refine the FRs in preparation for the ensuing stages of development and testing. Nevertheless, to accommodate the desired levels of personalisation there may be a requirement to sacrifice the complexity of the evaluation as each system will be highly attuned to each patient's individual needs and preferences hence making it extremely difficult to make comparisons across all patients on all three sites. At present we are aware of this situation and will offer some restrictions on what can and what cannot be personalised in the next version of the system to still provide a reliable and robust evaluation across all users. Our current technical work is focusing on the revision of the cognitive prosthetics from a technical perspective along with the development of methods and tools to capture the user's desires for personalisation.

Acknowledgements

This work has been partially funded by the European Commission under grant 034025.

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An Integrated Approach to Context Specification and Recognition in Smart Homes

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Abstract. This paper introduces a framework for integrating ontology- and logic-based approaches for context-awareness in Ambient Intelligence. A context description language is described, which allows to easily specify patterns of events which occurrences are monitored by an actual system. As long as the system evolves, symbolic information originating from heterogeneous sources is aggregated and classified according to well-formed formulas. Experimental results in a Smart Home environment are presented and discussed.

1 Introduction

During the past few years, many research efforts were undertaken to improve the quality of life of elderly and people with special needs [3]. Intelligent environments are the key to achieve these goals: they are responsible for distributed data gathering, information extraction, situation representation and interaction with users, thus enabling the introduction into the real world of such technologies as remote healthcare [2] and intelligent surveillance [6]. The semantic information associated with the data flow is of the uttermost importance either for an intelligent monitoring system or for a human caregiver to infer user conditions and to give immediate assistance. Typical requirements include: (i) intelligent interfaces must present information originating from ontologies to capture the meaning of the collected data; (ii) caregivers and system designers must be able to easily specify the overall system behavior. With respect to these requirements, a high-level symbolic representation for describing both the desired system behavior and the current status of the environment must be realized.

This paper proposes a framework aimed at integrating the benefits of ontology- and logic-based approaches for context-awareness in AmI applications. Based on previous work [9], we assume the availability of a system providing an ontology with information originating from distributed sources. In particular, we introduce a context description language, called $\mathcal{CDL}$, suitable to fill the gap between behavior specification and context-awareness algorithms. The paper is organized as follows: first, relevant literature is discussed; next, the reference architecture, the proposed ontology an the representation language for context modeling are introduced; finally, experimental results performed in a Smart Home set-up are reported. Conclusion follows.

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 26–33, 2008.

2 Related Work

In literature, there is no widespread agreement about how to model contexts. However, a number of basic requirements must be addressed: (i) context structures must be used to classify actual information; (ii) they can be composed to generate more complex representations; (iii) they must grasp both relational and temporal relations among events. The current debate identifies ontology- and logic-based approaches.

Ontology-based models [10] are characterized by a superior expressiveness in describing concepts and relationships. These models, called ontologies, can be used by computational algorithms, and have been exploited to model real-world high-level contexts [8] and specific domains of interests [5][7]. Although ontologies offer a basic framework for supporting reasoning, they currently lack in generality (as they focus on specific domains) and extensibility (since context models can not be easily aggregated to build more complex representations).

Logic-based approaches manage contexts using facts which are stated or inferred from a given set of rules. In particular, [4] identifies two main principles: (i) [illegible]: reasoning must occur within a domain defined by a context; (ii) cross-domains [illegible]: relationships can occur between reasoning activities belonging to different contexts. Several logic-based architectures have successfully been designed and made effective, e.g., based on temporal relationships to assist human decision making in a healthcare scenario [1]. Despite the powerful reasoning capabilities offered by logic-based approaches, they are not suited to grasp the general relationships among entities in a compact way.

3 $\mathcal{CDL}$: A Context Description Language

3.1 An Architecture for Data Acquisition

An [illegible] is a distributed system where several entities cooperate to perform data gathering and context acquisition [9]. When dealing with ontology- or logic-based approaches, context-awareness requires techniques aimed at grounding numerical data to symbolic representations. In [9], a simple and effective design choice is adopted to support symbol grounding: only [illegible] sensors, i.e., sensors providing boolean or ordered information, are used, since corresponding data can be easily translated into symbols.

All the involved activities are performed by properly designed agents. Each agent is characterized by a [illegible], a [illegible] (e.g., used to establish a communication with the agent itself), and a number of [illegible]. These data are stored within an [illegible], managed by an [illegible] service (see Figure 1). Whenever an agent is looking for a source of information, it queries the agent-directory for produced message types: once the resource has been selected, a communication link is established using a [illegible] service. The message-transport service maintains data structures in order to ground [illegible] contents with respect to the ontology.

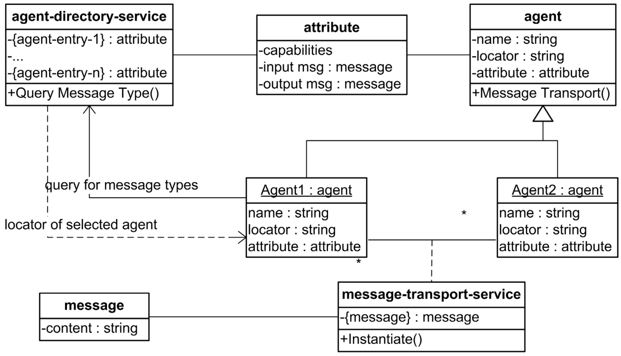

Fig. 1. A representation of the system architecture

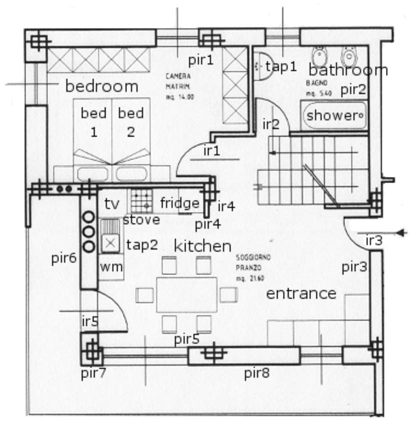

Fig. 2. A typical reference scenario

3.2 A Reference Scenario

Our reference environment (see Figure 2) comprises a `bedroom`, a `bathroom` and a living room, which is divided into two areas, namely `entrance` and `kitchen`. Several `ir` (i.e., infra red) sensors are placed in both doorways and passages, whereas `pir` sensors monitor interesting areas. Furthermore, we reasonably assume the availability of `temperature`, `bed` and `tap` sensors, and a number of intelligent appliances (e.g., `stove`, `fridge`, `shower` and `tv`). It is worth noticing that all the devices are either commercial products or they can be easily obtained (e.g., a [illegible] on a seat generate a [illegible]). For the sake of simplicity, we assume a single user scenario.

The system is designed to monitor the occurrence of specific contexts, i.e., collections of simultaneous events (i.e., [illegible] contexts) or distributed over different periods of time (i.e., [illegible] contexts). For example, [illegible] could be modeled as a collection of [illegible] including [illegible]

[illegible], [illegible] and [illegible], which must occur either simultaneously or in sequence to infer that the user is taking lunch.

3.3 The Ontology Representation

The main goal of context assessment is to arrange information originating from distributed agents in templates relating numerical data to symbols. This process is handled by the [illegible] agent, which maintains a knowledge base Σ that is represented using a Description Logic (DL for short), such that $\Sigma =$ `<TBox,ABox>`. Reasoning capabilities are based on [illegible]. The main purpose of Σ is twofold: (i) to manage a process of symbolic information fusion for assessing information [9]; (ii) to store instances of constants, variables, functions, predicates and terms for specifying the context definition language $\mathcal{CDL}$. Σ can be divided into five main [illegible].

[illegible] $\Sigma \models$ `Entity` is used to group $\{$`Agent`, `Action`, `User`, `Area`, `Object`$\} \sqsubseteq$ `Entity`, in order to represent shared descriptions for subsumed concepts.

[illegible] This part represents definitions and instances of `Agent` and `Data` which are exchanged within the system. An explicit representation is fundamental since it realizes both an [illegible] service and – with respect to instances of `Data` – a repository for [illegible] used by $\mathcal{CDL}$. Examples of `Data` instances include $\Sigma \models$ `Data(pir-data)` or $\Sigma \models$ `Data(temp-data)`.

[illegible] $\Sigma \models$ `User` models users, which are assumed to be identified by matching, e.g., RFID tags with predefined labels.

[illegible] It includes concepts which are used to describe the physical space, e.g., $\Sigma \models \{$`Area`, `Sensor`, `Actuator`, `Furniture`$\}$. Relevant objects include areas, e.g., `Area(bedroom)` or `Area(bathroom)`, several devices, e.g., `PIR(pir`$_1$`)`, `Tap(tap`$_1$`)` or `Seat(seat`$_2$`)`, or [illegible] furniture, such as `Stove(stove)`, `Fridge(fridge)` or `Bed(bed`$_1$`)`. With respect to $\mathcal{CDL}$, instances of this class constitute [illegible].

[illegible] A $\Sigma \models$ `Predicate` describes [illegible] about the state of an `Entity`, which semantics depends on an interpretation $\mathcal{I}$. As long as a_i, such that $\{a_i | \Sigma \models \texttt{Data}(a_i), i = 1, ..., |\texttt{Data}|\}$ are updated with new sensor information (i.e., a variable assignment α over the `ABox` is defined), then corresponding p_j, such that $\{p_j | \Sigma \models \texttt{Predicate}(p_j), j = 1, ..., |\texttt{Predicate}|\}$ are updated as well. As a consequence, their truth values change accordingly. Useful instances include `Predicate(pir-active)`, `Predicate(tap-open)` and `Predicate(seat-pressed)`.

$\Sigma \models$ `Situation` relates an `Entity` to one or more `Predicates`, whereas, according to a multi-context perspective [4], a clearer picture of the situation can be inferred by considering the union of relevant `Situation` instances. A `Context` is an aggregate of one or more `Situation` concepts. Therefore, `Contexts` $\Sigma_c \in \Sigma$ are formulas which are described in $\mathcal{CDL}$.

Given an interpretation $\mathcal{I}$, $\texttt{Context}^{\mathcal{I}}$ is given by the conjunction of the semantics of the various constituent $\texttt{Situation}^{\mathcal{I}}$ and $\texttt{Predicate}^{\mathcal{I}}$. However, more can be [illegible] from the mere conjunction of `Predicate` instances. For example, consider `Predicate(stove-active)`, `Predicate(pir`$_4$`-active)` (assuming that `pir`$_4$ is located in the `kitchen`) and `seat`$_1$`-pressed`: when considered as a whole, it is likely that someone is going to [illegible].

The corresponding `ABox` maintains the status of the system at . Specifically, for each time instant t, a different variable assignment α_t is used over `Predicate` instances. A properly defined individual, i.e., `history` $\sqsubseteq \top$, explicitly stores these instances occurred within a predefined temporal window of lenght n. As long as the system evolves, it happens that $(\Sigma, \mathcal{I}, \alpha_t) \vdash_i \Sigma_c^i($`history`$)$, i.e., `history` by a number of `Contexts` Σ_c^i. When this happens, these contexts are detected.

3.4 A Language for Describing Contexts

$\mathcal{CDL}$ is a two-way representation between Σ and system designers. From the Σ side, $\mathcal{CDL}$ is grounded with respect to concepts, roles and instances in Σ. From the designer side, as contexts are described using $\mathcal{CDL}$, new concepts instances are created within Σ and immediately used to check subsumption with respect to `history`. Hereafter, we assume the availability of the operator ξ: given a concept $\mathcal{C}$, $\xi\mathcal{C} = \{c_i | \Sigma \models \mathcal{C}(c_i), i = 1, ...|\mathcal{C}|\}$, i.e., all the individuals subsumed by $\mathcal{C}$.

. $\mathcal{CDL}_v$ is a possibly infinite enumeration of symbols which change over time as a consequence of a variable assignment α_t. These symbols are mapped to ξ`Data` and ξ`Period`. Examples of ξ`Data` include either (e.g., `pir`$_i$`-data`, $i = 1, ..., 8$, `smoke-data` or `stove-data`), or (e.g., `temp-data`) domains. Each `Predicate` is satisfied by (Σ, α_t) for a given `Period`.

. $\mathcal{CDL}_c$ is a possibly infinite enumeration of symbols which are closed with respect to α_t. They are mapped to ξ`Device` and to thresholds used to discretize `Device` values originating in ordered domains. Examples of ξ`Device` include `pir`$_i$, $i = 1, ..., 8$, `smoke`, `stove` and `ir`$_i$, $i = 1, ..., 5$. Thresholds commonly used include, e.g., those for temperature or light sensor data.

. $\mathcal{CDL}_p$ is a possibly infinite enumeration of symbols which are explicitly interpreted according to a semantics $\mathcal{I}$. They are either directly mapped to ξ`Predicate` or to immediately inferred facts. Interesting predicates include: `pir`$_i$`-active` (and similar for `smoke`, `ir` or `stove` devices), or `temp-cold` (and similar for other ordered sensors, such as, e.g., `light`). Temporal duration is modeled using the λ of a `Predicate`, i.e., a `Predicate` which is satisfied whenever the `Period` associated with the monitored `Predicate` exceeds a threshold τ. For example, we refer to the `Predicate` monitoring the length of `smoke-active` using λ`smoke-active`. Furthermore, we introduce the δ of a `Predicate`, i.e., a `Predicate` which is satisfied when a given monitored `Predicate` changes its status from to (or) at the time instant t. For example, we refer to the `Predicate` monitoring the activation of `pir`$_i$ using δ`pir`$_i$`-active`$^{f \rightarrow t}$.

. $\mathcal{CDL}_f$ is a possibly infinite enumeration of symbols modeling the relationships among ξ`Predicate`, ξ`Situation` and ξ`Context`. Symbols in $\mathcal{CDL}_f$ are mapped to roles within Σ. For example, recall the `Context`: the constituent predicates `stove-active`, `pir`$_4$`-active` and `seat`$_1$`-pressed` are related to a corresponding `Context` through the roles `doing`, `where` and `pose`, i.e., ξ`TakeLunch` $\sqsubseteq$ `Context` $\sqcap \exists$`doing.stove-active` $\sqcap \exists$`where.pir`$_4$`-active` $\sqcap$ $\exists$`pose.seat`$_1$`-pressed`.

$\mathcal{CDL}_{cs}$ is a finite enumeration of propositional connectors, including:

- : $\neg$ (i.e., negation), $\sqcap$ (i.e., DL-like conjunction) and $\sqcup$ (i.e., DL-like disjunction).
- : $\sqsubseteq$ (i.e., subsumption) and $\times$ (i.e., role filling). Subsumption is the main reasoning scheme provided by DLs. Given two concepts $\mathcal{C}_1$ and $\mathcal{C}_2$, we say that $\mathcal{C}_1$ is subsumed by $\mathcal{C}_2$ (and we write $\mathcal{C}_1 \sqsubseteq \mathcal{C}_2$) iff $\mathcal{C}_2$ is more general than or equivalent to $\mathcal{C}_1$. Role filling identifies associations between functions and constants or variables.
- : λ (i.e., length of a `Predicate`), δ (i.e., derivative of a `Predicate`) and $\overleftarrow{\sqcap} \sqsubseteq \sqcap$ (i.e.,). Specifically, $\overleftarrow{\sqcap}$ is used to concatenate sequences of predicative symbols which temporal relationship is important. For example, given $\mathcal{C}_1$ and $\mathcal{C}_2$, we say that $\mathcal{C}_1 \overleftarrow{\sqcap} \mathcal{C}_2$ is true iff $\mathcal{C}_2$ occurs before $\mathcal{C}_1$.

$\mathcal{CDL}_w$ comprises terms and formulae. Terms represent partial descriptions of concepts, whereas formulae are properly defined concepts. In order to specify ξ`Context`, a designer is requested to write formulae, according to the specifications of $\mathcal{CDL}$. A term is defined as follows: (i) a generic symbol $x \in \mathcal{CDL}_v$ is a term; (ii) a generic symbol $a \in \mathcal{CDL}_c$ is a term; (iii) if $f \in \mathcal{CDL}_f$ is a function, and $t_1, ..., t_2 \in \mathcal{CDL}_w$ are terms, then $f \times t_1 \times ... \times t_n$ is a term. Terms are useful in order to build more complex formulas. In particular, an formula is a word in the form $p(t_1, ..., t_n)$, where $p \in \mathcal{CDL}_p$ and $t_1, ..., t_n \in \mathcal{CDL}_w$. Therefore, a formula is defined as follows: (i) atomic formulas $p \in \mathcal{CDL}_w$ are formulas; (ii) if $A \in \mathcal{CDL}_w$ is a formula, then $\neg A \in \mathcal{CDL}_w$ is a formula; (iii) if $A, B \in \mathcal{CDL}_w$ are formulas, then $A \sqcap B \in \mathcal{CDL}_w$ and $A \sqcup B \in \mathcal{CDL}_w$ are formulas (please notice that, as $\overleftarrow{\sqcap} \sqsubseteq \sqcap$ holds, also $A \overleftarrow{\sqcap} B \in \mathcal{CDL}_w$ is a formula); (iv) if $A \in \mathcal{CDL}_w$ is a formula, then $\lambda A \in \mathcal{CDL}_w$ and $\delta A \in \mathcal{CDL}_w$ are formulas.

4 Examples and Discussion

The designed experiments have been implemented at the Know-House@DIST set-up [9]. Each Figure represents an example of activation pattern for the related context obtained with real data.

$\mathcal{C} \sqsubseteq$ `Context` $\sqcap$ (`bed`$_1$`-pressed` $\sqcup$ `bed`$_2$`-pressed`) $\sqcap$ `shower-active`. Although $\mathcal{C}$ is a relational context, this definition subsumes more complex patterns in `history`, such as, e.g., `bed`$_1$`-pressed`$\overleftarrow{\sqcap}$`ir`$_1$`-active`$\overleftarrow{\sqcap}$`ir`$_2$`-active` $\sqcap$ `shower-active`: i.e., the user left the `bathroom` and went to the bed forgetting the `shower` opened (refer to Figure 2 to track user movements). In other words, $\mathcal{C}$ subsumes all the descriptions subsumed by the constituent formulae (i.e., instances of `Predicate`).

: $\mathcal{C} \sqsubseteq \lambda$`bed`$_1$`-pressed`$\overleftarrow{\sqcap}\delta$`bed`$_1$`-pressed`$^{f \rightarrow t}$. In order to $(\Sigma, \mathcal{I}, \alpha_t) \vdash \mathcal{C}($`history`$)$, a change in the truth value of `bed`$_1$`-pressed` must be detected. Then, the of `bed`$_1$`-pressed` is checked: if it exceeds the

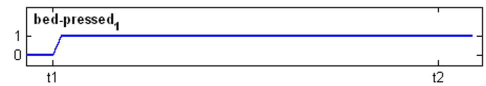

Fig. 3. Behavior of `bed`$_1$`-pressed` in Experiment 2

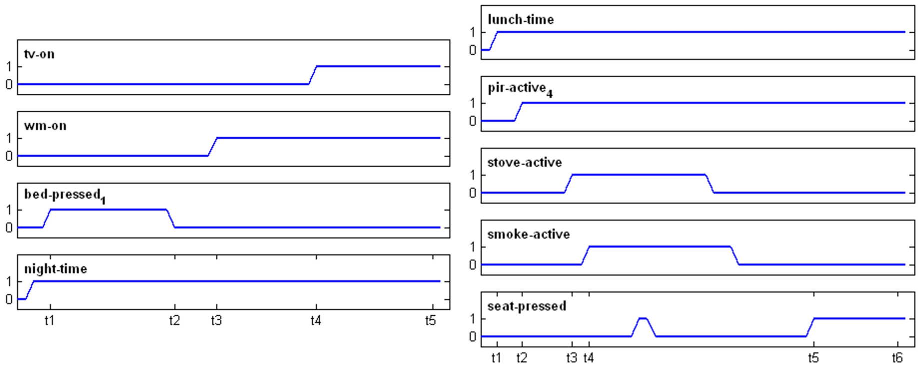

Fig. 4. Behavior of relevant predicates in Experiments 3 and 4

threshold τ, λ`bed`$_1$`-pressed` is satisfied, and then $\mathcal{C}$ is satisfied as well. Only one `Predicate` in Σ is really involved in practice, i.e., `bed`$_1$`-pressed` (see Figure 3).

[illegible]: $\mathcal{C}$ = `night-time` $\sqcap$ λ`tv-on`$_\tau$ $\overleftarrow{\sqcap}$ δ`tv-on`$^{f\rightarrow t}$ $\overleftarrow{\sqcap}$ δ`bed-pressed`$_1^{t\rightarrow f}$ $\overleftarrow{\sqcap}$ λ`bed-pressed`$_{1,\tau}$. If `history` were to contain, among other events, λ`tv-on`$_\tau$ $\overleftarrow{\sqcap}$ δ`tv-on`$^{f\rightarrow t}$ $\overleftarrow{\sqcap}$ δ`wm-on`$^{f\rightarrow t}$ $\overleftarrow{\sqcap}$ δ`bed-pressed`$_1^{t\rightarrow f}$ $\overleftarrow{\sqcap}$ λ`bed-pressed`$_{1,\tau}$ $\sqcap$ `night-time` (i.e., the washing machine is used during the night) it would be equally subsumed by $\mathcal{C}$, [illegible] `history` $\sqsubseteq \mathcal{C}$ holds because of the events occurring in t_1, t_2, t_4 and t_5 (see Figure 4 on the left). Therefore, it is possible to note that formulae describe the minimal amount of information to be satisfied for the relative context to be detected.

[illegible]: $\mathcal{C}$ = `lunch-time` $\sqcap$ λ`seat-pressed`$_{1,\tau}$ $\overleftarrow{\sqcap}$ δ`seat-pressed`$_1^{f\rightarrow t}$ $\overleftarrow{\sqcap}$ (`oven-time` $\sqcup$ (δ`smoke-active`$^{f\rightarrow t}$ $\overleftarrow{\sqcap}$ δ`stove-active`$^{f\rightarrow t}$)) $\sqcap$ δ`pir-active`$_4^{f\rightarrow t}$. In other words, the user is detected to be [illegible], then [illegible] and finally [illegible]. The patterns in Figure 4 on the right are subsumed by $\mathcal{C}$, thus depending only on events occurring in t_1 to t_6. It is worth noticing that alternatives can be considered as well: $\sqcup$ is used in those contexts taking alternative conditions into account.

5 Conclusion

This paper presented an integrated ontology- and logic-based framework for contexts specification and acquisition. In particular, the system behavior can be formalized using a high-level language, called $\mathcal{CDL}$, which is grounded with respect to an [illegible]. Specifically, [illegible] belonging to $\mathcal{CDL}$ are mapped into concepts and relationships, which are used to classify actual data patterns. Using [illegible], the system exhibits important desirable features: (i) contexts to be detected do not have to be fully specified, as more complex patterns of events are subsumed by generic context descriptions; (ii) symbolic [illegible] are implicitly filtered away, as patterns with false positives are subsumed by more general descriptions. The experimental results performed in a real set-up confirm these properties. Although the system has been applied to AmI-related scenarios, its generality allows for its use in similar research fields as well, e.g., mobile robotics based surveillance and intelligent man-machine interfaces.

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Robust Face Tracking with Suppressed False Positives in Smart Home Environment

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Abstract. The face-tracking systems in use often suffer from converging to a false face-like region in a smart home environment. For this, we propose a technique to reduce errors due to false positives in the estimation scheme of face movement. In the proposed method, the face movement is estimated by using the information on face-candidate blobs obtained from the current frame as well as from the previous frame. This estimated face movement information is used in the face tracker for tracking faces in video images. Our experimental result shows a conspicuous improvement in the performance of the face tracking process in terms of success rates and with robustness against interruptions from face-like blobs.

Keywords: Face tracking, face movement estimation, robustness.

1 Introduction

Tracking of human faces in a smart home may be applied to a wide range of applications including human intention reading and human-machine interaction/ interface in a restricted space [1, 2]. When a human face-tracking system begins searching for a face in a given scene, the tracker may wrongly converge to a local maximum that corresponds to a face-like region around the face [3]-[8]. Various attempts have been made to avoid the problem. A typical approach [3, 4] is to employ multiple visual cues such as color, frame difference, and previous face location, and exclude such a false face-like region in the face tracking process. But, the known algorithms often show that some false positive blobs, such as moving hands and skin-colored shirt, are not easily excluded, leading the tracker to converge to those regions.

To deal with such an unpleasant convergence problem, we propose to estimate the face movement in an earlier phase and use the information for more reliable localization of face. With such information, the tracker will be shown to be robust against interruptions from face-like blobs and hardly converge to a local maximum. To be more specific, let us first recall that, in most face tracking processes, the face motion is described by the state $\mathbf{x}(k)$ of a face in the k^{th} frame specified as:

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$$\mathbf{x}(k) = \left(\mathbf{y}(k),\ \Delta\mathbf{y}(k)\right) \tag{1}$$

$$\text{or } \mathbf{x}(k) = \left(\mathbf{y}(k),\ \Delta\mathbf{y}(k),\ \Delta^2\mathbf{y}(k)\right) \tag{2}$$

where $\mathbf{y}(k)$ is a two-dimensional vector which indicates the center of gravity (COG) of the face, and $\Delta\mathbf{y}(k)$ and $\Delta^2\mathbf{y}(k)$ represent the corresponding velocity and acceleration, respectively, in the k^{th} frame. In order to track the face position in the current frame k, it is assumed that the estimated state $\hat{\mathbf{x}}(k)$ and the state $\mathbf{x}(k\text{–}1)$ in the $(k\text{–}1)^{th}$ frame are related, along with some noise process $\mathbf{v}(k)$, as in the dynamic equation of the form

$$\hat{\mathbf{x}}(k) = f\left(\mathbf{x}(k-1),\ \mathbf{v}(k)\right), \quad k{=}1, 2, \ldots. \tag{3}$$

and the measurement equation is given by

$$\hat{\mathbf{y}}(k) = h\left(\hat{\mathbf{x}}(k), \mathbf{n}(k)\right) \tag{4}$$

where each of the noise sequences $\{\mathbf{v}(k)\}$ and $\{\mathbf{n}(k)\}$ is assumed to be independent and identically distributed [5]-[8]. With a proper estimation scheme specified, the tracking process then begins searching for the face at the predicted location $\hat{\mathbf{y}}(k)$ in the face localization phase.

In the above dynamic equation (3), it is implied that $\hat{\mathbf{y}}(k)$ is computed by using $\mathbf{y}(k\text{–}1)$, $\Delta\mathbf{y}(k-1)$, and sometimes $\Delta^2\mathbf{y}(k-1)$. Good estimation may be achieved if the process is linear or simple enough. Face movement in natural situations is, however, often nonlinear and likely to involve sudden accelerations, reversal of rotations, and changes in orientation. Thus, this type of face movement model (Eq. (3)) that relies on the information only in the previous frame(s) shows limitation in accurate estimation of face movements. Moreover, the actual modeling process can be quite complicated when the moving objects in 3D are projected on the 2D image plane of a camera. Even if a localization operation, such as mean-shift [6]-[8], is performed subsequently, the tracker may converge to a local maximum when face-like objects are in or near the inaccurately predicted location.

In this paper, we show that the face movement is estimated fairly well by utilizing the information of the current input image obtained just prior to the face localization phase as well as information of the previous frame of an image. If we denote the face movement and information in the image at the current frame k as $\mathbf{m}(k)$ and $\mathbf{I}_i(k)$, respectively, this process of face movement estimation would be expressed as an equation of the form:

$$\mathbf{m}(k) = p\left(\mathbf{I}_i(k),\ \mathbf{I}_i(k-1)\right) \tag{5}$$

During this proposed estimation phase, the face-candidate blobs are extracted by using the often-used cues of skin color and motion contained in the current frame and the previous frame, respectively, to estimate the face movement. To date, these cues are known to have been used only for face localization [6, 7]. And then, we shall use this information of $\mathbf{m}(k)$, together with $\mathbf{y}(k–1)$, to estimate the face location. The proposed estimation scheme may be described by a functional relation as follows:

$$\hat{\mathbf{y}}(k) = g\big(\mathbf{y}(k-1), \mathbf{m}(k),\ \mathbf{n}(k)\big) \quad (6)$$

By comparison, one may easily notice that the proposed estimation scheme (6) is different from the conventional methods of (4).

This paper is organized as follows. In Section 2 is described the proposed method of estimating face movement. The overall face-tracking scheme is presented in Section 3 and its performance is demonstrated via experimental results in Section 4. Finally, some concluding remarks are provided in Section 5.

2 Face Movement Estimation Phase

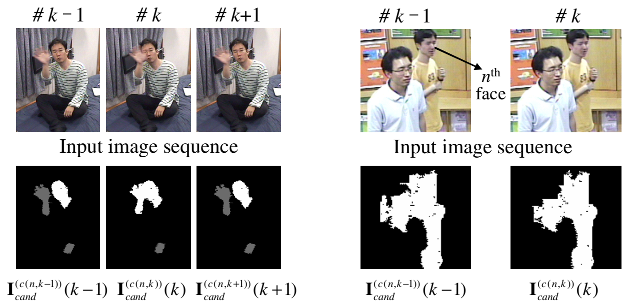
2.1 Selection of a Candidate Blob

Let N denote the number of faces in the sequence of images and the face tracker is assumed to be capable of tracking any of them once designated. The tracker is also assumed to use the skin color and motion information as the salient cues. To be specific, let the system to track the n^{th} face among N faces. In the tracking process, the tracker system would first identify those regions in the image with both skin color and motion cues, which are called the *face-candidate blobs* [9]. Among these multiple candidate blobs, we are interested in a particular candidate blob, called the *best candidate blob*, with the largest occluded region on the n^{th} face region of the previous $(k–1)^{\text{th}}$ frame to track the n^{th} face in the k^{th} frame. Here, the best candidate blob for the n^{th} face tracking in the k^{th} frame can be identified by the number $c(n,k)$. Thus, the system proceeds to select the best candidate blob whose identification number is designated as $c(n,k)$ and use it for estimation of face movement.

2.2 False Positive Blobs

Among many types of cues, the skin color and motion cue are known to reduce quite effectively the possibility of converging to a local maximum in the process of extracting the best candidate blob. However, the extracted candidate blob may still be affected by some false positives such as a moving hand or a nearby skin-colored object. When estimation of face movement is inaccurate, such false positives may cause the tracker to converge to one of those false regions.

Regarding false positive blobs, we point out that, among several possible forms, there is a quite conspicuous type that may affect the estimation in a very negative way. It is the blob that is generated due to temporal merging of a skin-colored object with face in the current frame k, as shown in Fig. 1 (a). Specifically, consider variation of COG of the best candidate blob between two frames of the previous frame and the current frame, which we shall use in estimating the face movement as further explained shortly. When the skin-colored object (for example, a hand) is merged with the n^{th} face blob in the k^{th} frame, we observe that, compared with $\mathbf{I}_{cand}^{(c(n,k-1))}(k-1)$, COG of $\mathbf{I}_{cand}^{(c(n,k))}(k)$ has moved toward the merged false positive blob, which would lead to a tracking failure that the tracker converges to the merged false positive blob in the face localization phase.



(a) Temporal merging and demerging (b) Spatial merging

Fig. 1. False positives in k^{th} frame

Note that, when it demerges from the face blob as shown in the $(k+1)^{\text{th}}$ frame of Fig. 1 (a), on the other hand, the COG of $\mathbf{I}_{cand}^{(c(n,k+1))}(k+1)$ moves toward the opposite direction from the demerged false positive blob. Even though this process of demerging does not involve any exact estimation of face movement, the tracker moves toward the estimated direction and tends to track the face in the face localization phase.

There is another type of false positive blob that is formed by spatial merging of some skin-colored object with face. Fig. 1 (b) shows the case that face is merged with a skin-colored shirt. Some irregular change in the shape of the merged false positive blob has occurred by the occlusion of movable objects, which results in wrong estimation of the face movement and eventually renders undesired convergence to the false positive blob.

2.3 Face Movement Estimation

In order to estimate face movement more accurately against the false positive blobs of spatial and temporal types described in Section 2.2, we propose to utilize the variation of the candidate blob positions between the current frame and the previous frame. Here, two techniques are considered in calculating COG variation of the best candidate blob.

To minimize negative effect due to the spatial type of false positive blob, the ROI (Region of Interest) for the n^{th} face tracking in the k^{th} frame, denoted by $ROI^{(n)}(k)$, is specified as the rectangular region that surrounds the n^{th} face region of the $(k-1)^{\text{th}}$ frame with a small margin.

Secondly, to prevent from being affected by the temporal type of false positive blob, we compare $\mathbf{I}_{cand}^{(c(n,k))}(k)$ within $ROI^{(n)}(k)$ with $\mathbf{I}_{cand}^{(c(n,k-1))}(k-1)$ within $ROI^{(n)}(k)$ and ignore any new foreground region appeared in $\mathbf{I}_{cand}^{(c(n,k))}(k)$, which was background region in $\mathbf{I}_{cand}^{(c(n,k-1))}(k-1)$. Thus, for calculating the face movement with robustness, the best candidate blob in the current frame is to be

$$\mathbf{I}_{cand}^{(c(n,k))}(k) \cap \mathbf{I}_{cand}^{(c(n,k-1))}(k-1) \text{ within } ROI^{(n)}(k) \tag{7}$$

while the best candidate blob in the previous frame is

$$\mathbf{I}_{cand}^{(c(n,k-1))}(k-1) \text{ within } ROI^{(n)}(k). \tag{8}$$

Now, we define "**m**(n, k)" to be the movement of the n^{th} face in the k^{th} frame, and use it in estimating the face location as in (9):

$$\begin{aligned}\mathbf{m}(n,k) = \alpha\big(&COG(\mathbf{I}_{cand}^{(c(n,k))}(k) \cap \mathbf{I}_{cand}^{(c(n,k-1))}(k-1) \text{ within } ROI^{(n)}(k)) \\ &- COG(\mathbf{I}_{cand}^{(c(n,k))}(k-1) \text{ within } ROI^{(n)}(k))\big)\end{aligned} \tag{9}$$

Here, we assume that $\mathbf{I}_{cand}^{(c(n,k))}(k) \neq 0$, $\mathbf{I}_{cand}^{(c(n,k-1))}(k-1) \neq 0$, and $1 < \alpha < 2$. If $\mathbf{I}_{cand}^{(c(n,k))}(k) = 0$, then $\mathbf{m}(n,k) = 0$. And if $\mathbf{I}_{cand}^{(c(n,k-1))}(k-1) = 0$, we set $\mathbf{I}_{cand}^{(c(n,k-1))}(k-1) \leftarrow \mathbf{I}_{cand}^{(c(n,k-2))}(k-2)$. If the temporal type of false positive blob does not exist and thus is not taken into consideration, we find that the estimated movement **m**(n, k) in (9) becomes the following expression:

$$COG\big(\mathbf{I}_{cand}^{(c(n,k))}(k) \text{ within } ROI^{(n)}(k)\big) - COG\big(\mathbf{I}_{cand}^{(c(n,k))}(k-1) \text{ within } ROI^{(n)}(k)\big) \tag{10}$$

Note that **m**(n, k) calculated in (9) only reflects the movement by the disappeared region in the current frame. Thus, α is required to compensate the estimation error due to the newly appeared, but ignored, region in the current frame. We remark that, if α is near to 2, the tracker may be strongly affected by the temporal type of false positive blob while, if α is close to 1, it may not follow the target due to a slight movement of the tracker in the estimated direction. In our experiment, we set $\alpha = 1.5$

3 Tracking Procedure

The overall tracking process is shown in Fig. 2, in which the proposed phase of selecting the best candidate blob and estimating the face movement in the k^{th} frame is added to the well-known procedure of face tracking [8].

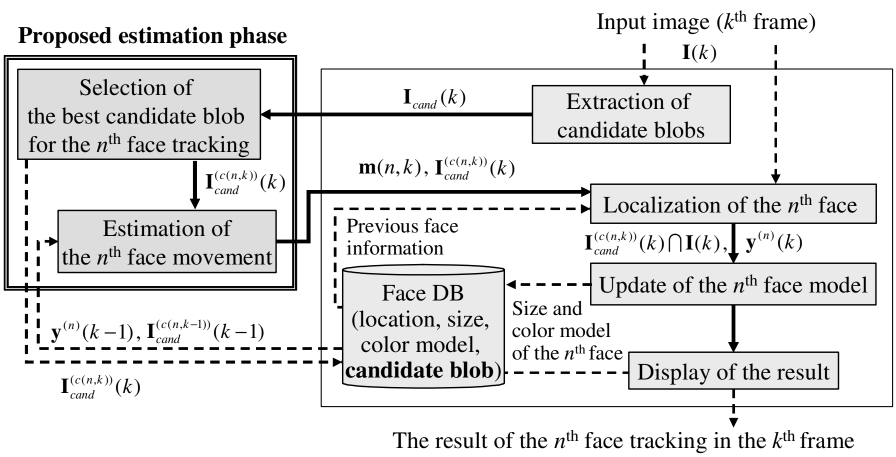


Fig. 2. Overall face tracking procedure for tracking n^{th} face in k^{th} frame

4 Experimental Results

In our experiment, the n^{th} face tracker of the face localization phase begins searching for the face at the estimated location by using the following equation:

$$\hat{\mathbf{y}}^{(n)}(k) = \mathbf{y}^{(n)}(k-1) + \mathbf{m}(n,k) + \mathbf{n}(k) \,. \tag{11}$$

Then, the cues of skin color, motion, and information about previous face location are employed to localize the face and update the face model in the face localization and update phases, respectively. The last phases follow the conventional deterministic tracking procedure [8].

As for the detection of a tracking failure, the n^{th} tracker is eliminated when the n^{th} face tracker is motionless or the skin color ratio within the tracked region is low for several consecutive frames.

The face tracking process with the proposed estimation phase is compared with two conventional schemes that use a prediction phase [6, 7] for 100 image sequences with a frame resolution of 320□240 pixels on a P-IV 3.2GHz PC (6,208 frames, 8,453 labeled faces).

To be fairly compared with the proposed method, the conventional methods start the face localization process from the location predicted by a dynamic model of the form (4) with the other procedures carried out under the same conditions. The constant-velocity model [7] and the constant-acceleration model [6] are given in the following as in (12) and (13), respectively.

$$\hat{\mathbf{x}}^{(n)}(k) = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} \mathbf{x}^{(n)}(k-1) + \begin{bmatrix} T/2 \\ 1 \end{bmatrix} \mathbf{v}(k) \,. \tag{12}$$

Here, $\mathbf{x}^{(n)}(k) = \left(\mathbf{y}^{(n)}(k),\, \Delta\mathbf{y}^{(n)}(k)\right)$ and T is the time interval of the discrete system.

$$\hat{\mathbf{x}}^{(n)}(k) = \begin{bmatrix} 1 & T & T^2/2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix} \mathbf{x}^{(n)}(k-1) + \begin{bmatrix} T^2/4 \\ T/2 \\ 1 \end{bmatrix} \mathbf{v}(k) \,. \tag{13}$$

In the above, $\mathbf{x}^{(n)}(k) = \left(\mathbf{y}^{(n)}(k),\, \Delta\mathbf{y}^{(n)}(k),\, \Delta^2\mathbf{y}^{(n)}(k)\right)$.

The comparison results of the proposed automatic face detection/tracking process with the above-mentioned tracking processes are summarized in Table 1. As for the computational cost, we find that all three methods show very similar performance but are different in tracking success as shown in Fig. 3 as an example.

Table 1. Comparison results of automatic face detection/tracking process

Method	Success rate (%)	Processing time (ms/frame)
With the prediction phase using the constant-acceleration model [6]	86.2	17.6
With the prediction phase using the constant-velocity model [7]	88.6	17.3
With the proposed estimation phase	93.4	17.7

Rectangle: Face detected initially by the detection process [9]
Ellipse: Face tracked by the tracking process after detection

(a) With the prediction phase (constant-acceleration model)
(b) With the prediction phase (constant-velocity model)
(c) With the proposed estimation phase

Fig. 3. Example of comparison results

The three approaches work well for the image sequences where there are no skin-colored objects merged with faces. The conventional trackers with the prediction phase, however, often fail to track the face in the image where some moving skin-colored objects merge with the face, as shown in Fig. 3 (a) and (b), whereas the proposed method reveals good performance as shown in Fig. 3 (c).

5 Concluding Remark

By using the current-frame image data as well as previous ones, it is shown that the face movement can be estimated and used for an effective face localization phase in the face tracking process. By experiments, we find that the proposed estimation of face movement is quite effective and also robust against interruption from false positive blobs. Overall, when compared with conventional prediction-based approaches, the proposed face tracking technique has shown the performance of improved success rate in tracking by preventing convergence to a local maximum. To extend the result reported in this paper, we will elaborate in a further study our estimation scheme of (11) to cope with more complex tracking situations and feature extraction algorithm to minimize the false positive regions under various environmental conditions.

The proposed method is expected to be applied to human intension reading system or human-machine interface system in a smart home where face like regions exist. It is noted that the tracking process should be executed in a restricted area in consideration of privacy.

Acknowledgments

This work was partially supported by the SRC/ERC program of MOST/KOSEF (grant #R11-1999-008).

This work has been partially supported in Development of Standard on Constitutional Health Status.

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Adaptive Solutions for Access Control within Pervasive Healthcare Systems

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Abstract. In the age of mobile computing and distributed systems, healthcare systems are employing service-oriented computing to provide users with transparent accessibility to reach their distributed resources at anytime, anywhere and anyhow. Meanwhile, these systems tend to strengthen their security shields to ensure the limitation of access to authorized entities. In this paper, we examine mobile querying of distributed XML databases within a pervasive healthcare system. In such contexts, policies - as XACML - are needed to enforce access control. We study the reactivity of this policy in the case of a user demanding access to unauthorized data sources showing that the policy will respond negatively to user demands. Thus, we propose to employ an adaptive mechanism that would provide users with reactive and proactive solutions. Our proposal is accomplished by using the RBAC scheme, the user profile and some predefined semantics in order to provide users with alternative and relevant solutions without affecting the system's integrity.

Keywords: Access control, pervasive computing, adaptation, XACML.

1 Introduction

As new technologies direct toward user satisfaction and quality assurance, service-oriented computing is being more and more adopted by enterprises in order to ensure better functionality and easier service delivery to their clients. Pervasive computing has added a new dimension to quality assurance when it promised to users a transparent access to systems at anytime, anywhere and anyhow.

Providing an interoperable interaction within dynamic environments and distributed information sources is highly advantageous and that's why enterprises are turning their classical ***Enterprise Information Systems*** EIS into ***Pervasive Enterprise Information Systems*** PEIS as a fulfillment of their promises in improving the performance of their services and maintaining transparent interaction with users [2] this would increase the accessibility and usability of these dynamic environments.

In such open environments, systems tend to secure their resources against any attack and restrain access in order to provide information only to authorized users.

Security was usually disconnected from the business domain. Nowadays, with the deployment of ***Service-Oriented Architectures***, services are seamlessly interacting to

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exchange information flows. Thus, a great need rises to secure these transactions through different layers using organizational policies and practices (e.g. fine grained access control) in order to govern the loosely coupled interactions that take place.

Consequently, the vision of interoperability had two perspectives: the first is the user's perspective who demands for maximal accessibility considering it as the objective of using a service, while the second is the system's perspective which should ensure secure access to business resources and clients information.

The principal objective of ubiquity and pervasiveness is to ensure a transparent access to information sources that are distributed in different physical locations. So as users tend to obtain access from different locations and using different personal gadgets, PEIS guarantee their availability, portability and security by following interoperable service-oriented architectures and by enforcing fine-grained access control security policies like XACML ***eXtensible Access Control Markup Language*** which is an XML-based policy that manages decentralized control on distributed resources and can thus, centralize decision making within PEIS [16].

As interoperability can be a double-faced coin between accessibility and security [2], we highlight the importance of applying an adaptive layer within PEIS in order to guarantee system integrity and user satisfaction. Thus, we argue that in some situations PEIS should be adaptive and consider providing users demanding access to unauthorized elements with suggestions to other authorized pieces of information that are relevant to their demands and are accessible according to their privileges profile.

In this paper, we have chosen a scenario within healthcare applications where a user is in an urgent situation and trying to gain access to a part of a document that is located in the distributed healthcare resources. Knowing that the documents are semi-structured (represented in XML) and that the access control policy used is XACML with the RBAC scheme (Role Based Access Control), the expected response of the conflict resolution mechanism that XACML adopts will be "access denied".

Therefore, we propose to extend the XACML policy by including a service based query rewriter that would execute a failure recovery mechanism that would either respond in a reactive manner by giving the user the option to correct his query by showing him the specific parts that he has access to or in a proactive manner where the system exploits the user profile and some predefined semantics to reform and adapt the issued query and provide users with alternative authorized access paths to access requested information.

Our proposition aims to provide a level of adaptive security that would meet the user needs by taking into consideration the user profile (interests, preferences, location, device, etc.), the context in which he's using the service and the privileges granted to him (e.g. RBAC). Finally, we intend to show that adaptation isn't only beneficial from a user's perspective or a system's perspective but can also take an intermediate position between the both of them.

In this paper, we'll start by presenting pervasive healthcare systems and the importance of balancing access in these systems. Then, we continue with a state of the art about access control in pervasive systems. Next, we'll present a security challenging scenario that shows the struggle between accessibility and access control within a pervasive healthcare system. Finally, we'll justify our proposition by highlighting the importance of adapting query results not only to user preferences and needs but also to his access rights.

2 Pervasive Healthcare Systems

The vision of healthcare systems as Service-Oriented Applications came from the idea of viewing hospitals as enterprises that interact with different internal and external systems in order to provide adequate services to different clients connected by different means.

As information systems are becoming pervasive systems and aiming to be more responsive and adaptive to user mobility, new medical and healthcare systems have promoted a collaborative usage of patient's medical information through a distributed network; where the patient record has become a ***virtual record*** (digital record) that can be treated by different users in different physical locations.

The evolution of a central ***Electronic Health Record*** that can be accessed from different systems and connection lines has helped in reducing the volume of patient records that are archived redundantly and has helped to acquire online, up-to-date patient information whenever needed. This has highly affected the quality of patient treatment and the time consumed to retrieve patient record.

Integrating ubiquity in healthcare systems is promoting the emergence of ***Pervasive Healthcare Systems***. In such systems, the user will be able to access the system from anyplace at anytime and using different machines and connection technologies. As healthcare systems tend to Integrate highly developed technologies (mobile devices, RFID technologies, eTokens, Smart cards, wireless networks and adaptive middleware) in order to satisfy user needs, these systems aim to become pervasive.

Employing such technologies will support different applications and services like telemedicine, patient monitoring, location-based medical services, emergency response and management, pervasive access to medical data, personalized monitoring using health-aware mobile devices and would finally ensure lifestyle incentive management [18]. Such services promote the quality of healthcare systems and would have great effect on reducing medical coasts on the long term.

As shown in fig 1, pervasive healthcare systems aim to perform a real time transparent and interoperable access to online information sources that might be decentralized in different physical places; this accessibility might be ***local and direct*** such as the case of a doctor consulting the hospital's central database in order to retrieve the patient's record. Another case might involve an indirect access to external resources as the case of a home nurse consulting the patient's record by performing ***indirect access*** to the system's database using a web service for example. This indirect access might be also performed by an employee accessing the insurance company system in order to see the patient's status.

A third case might be the one of a doctor requesting access to a data stream of patient information existing ***on an external database*** residing on mobile devices held by a home nurse or by the patient at home (in order to monitor the patient status and progression).

Healthcare data should be available and accessible at anytime, anywhere but their access should be restricted to authorized people. Pervasive healthcare applications will help health providers, such as major hospitals, to achieve the level of data quality required without spending high investments in information infrastructures.

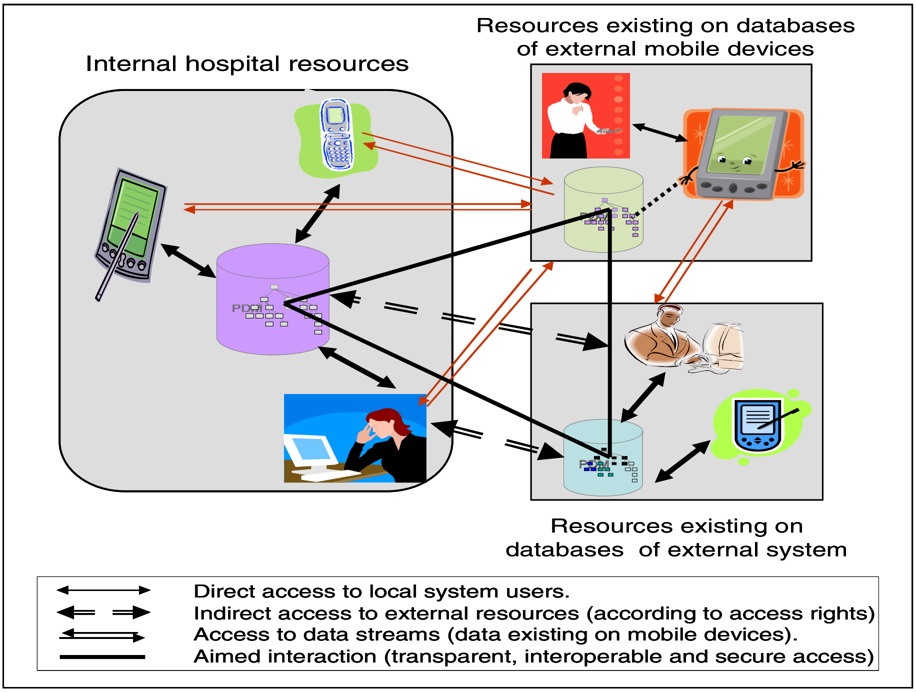

Fig. 1. Access modalities within Pervasive Healthcare Systems

In order to share patient information, medical centers tend to perform record transactions or to access medical records of external resources. Ensuring the patient privacy in such operations is very important and therefore any record transfer should be justified and any record access should only be allowed in particular purposes.

Finally, as we have illustrated the various interaction modalities that can take place, we highlight that the objective of a pervasive system is to provide transparent transactions within the system and to ensure seamless interaction between the user and the system in order to provide him with maximum accessibility to data sources.
Next, we'll expose the different components of pervasive healthcare systems in order to find a way to secure access within these systems.

3 Access Control in Pervasive Environments

In pervasive environments, mobile users tend to request ubiquitous access to data from different terminals and under variable connection qualities. Being in the age of multimedia, data is heterogeneous in kind (comes in different forms and formats) and also in source (it could be located in different places within decentralized systems or coming from different sources).

In order to achieve transparent access and facilitate data distribution, the W3C introduced XML eXtensible Markup Language as a standard for data representation and exchange [6].

Accessibility within pervasive environments is attained using unreliable connectivity channels. That's why access control is highly needed and is considered as an efficient way to restrict access to unauthorized users. In the context of controlling access to XML documents and databases, pervasive services should employ secure and efficient mechanisms to protect sensitive data against exposure.

Different authorization mechanisms were proposed to perform centralized access control to XML documents [4, 7, 9, 10, 13]. As we are moving towards mobile and decentralized access to data, [5] has proposed to move access control to the client side justifying that in the past, client devices weren't trustworthy so all client-based access control solutions relied on data encryption where the data are kept encrypted at the server and a client is granted access to subparts of them according to the decryption keys in its possession. Moreover, as centralized access controllers, these models had to minimize the trust required on the client's device by providing a static way of sharing data. The dynamic client-based evaluator of access control rules regulates access to XML documents and takes benefit from a dedicated index to quickly converge towards the authorized parts of a streaming document. The introduction of this method was justified by the emergence of hardware and software security.

These research works are efficient in the case of client-based access and when guaranteeing secure connection paths but with the emergence of pervasive computing, system are becoming more and more dependant on service-oriented computing and applications. That's why our works are interested in presenting a service oriented approach to ensure secure access to decentralized information sources containing semi-structured documents

In order to ensure secure transactions within PEIS, XACML ***eXtensible Access Control Markup Language*** was proposed by OASIS [14]. XACML provides an expressive security policy for data exchange within dynamic environments which enables a flexible way to express and enforce access control policies while exchanging data.

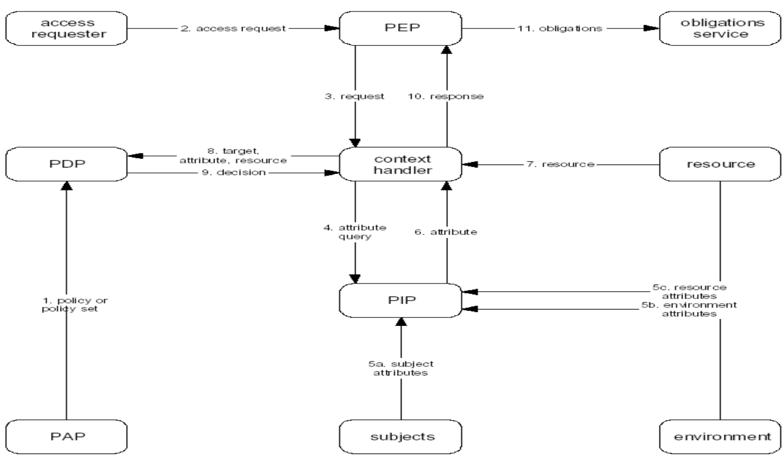

Fig. 2. OASIS XACML dataflow

As shown in fig 2, as a client makes a resource request upon a server; a PEP ***Policy Enforcement Point*** interferes to ensure a secure and authorized access. In order to enforce a security policy, PEP will formalize attributes describing the requester (these attributes can be extracted from the user profile) to the PIP ***Policy Information Point*** and delegate the authorization decision to the PDP ***Policy Decision Point***. Applicable policies are located in a policy store and evaluated at the PDP, which then returns the authorization decision. Using this information, the PEP can deliver the appropriate response to the client and ensures that only authorized resources are accessed [3].

From a business perspective, XACML is convenient to PEIS and serves as a decentralized service-oriented architecture that enables distributed settings of critical business rules and security policies. This is done by providing fine-grained access control that would take the business relationship contracts into account. In addition, the XACML authorization logic enables the abstraction of central applications so that an enterprise would be able to manage authorizations from central locations [16].

From a usability perspective, XACML allows a seamless decentralization but from a managerial decision making perspective, XACML ensures an interoperable interaction of different business policies and centralized decision making.

Access control has a significant importance in guaranteeing that employees are obtaining access according to their position in the organizational chart which is expressed as employee's role. Therefore, OASIS has defined a profile for the use of XACML in expressing policies for Role Based Access Control RBAC [15].

After mentioning the benefits of XACML as an interoperable security protocol for service oriented architecture, we'll present an introduction to healthcare systems as an example of a PEIS and we'll show the different challenges that face the interaction of their subcomponents.

4 Inspiring Scenario

The particularity of pervasive information systems lies in their composition of highly interactive subcomponents that cooperate seamlessly in order to satisfy user needs which is our essential motivation.

Our scenario takes place in a pervasive healthcare system and more precisely in an emergent case where a patient is being transported in an ambulance. The user of the system in this scenario is the treating nurse that is handling the patient in a critical status and trying to control his situation. In such context, the system would enable the nurse to gain access to authorized parts of the patient record which exists in the system's database. This access is usually controlled to maintain the system's integrity.

Our problem appears when the nurse connects to the system - using a mobile device - and executes a query to access a **non-authorized** attribute in the patient's record. A typical system response would be that access is **denied**. There, the nurse will try to make several requests for relevant elements that might or might not be authorized due to security constraints (attached to her role as a nurse). In such urgent cases, time is critical and there might be some authorized elements that could help the nurse in finding achieve her mission without breaking the rules.

Our proposition highlights the importance of having an adaptive service-oriented mechanism that would employ some predefined semantics in order to connect unauthorized attributes with others that are authorized and relative. This way, the nurse would have a reactive and proactive system providing alternative solutions that might answer demands in such cases.

5 Introducing Adaptation to Access Control

Our system's security policy will be based on XACML (eXtensible Access Control Markup Language) [14] following the RBAC model (XACML RBAC profile [15]).

The basic concept of the RBAC model [9] is to assign different actions to different groups of users. This is accomplished by giving groups of users certain roles, then assigning permissions to these roles and finally users would acquire permissions by being members of certain roles.

The definition of an RBAC model for an enterprise hierarchy offers many benefits such as the ease of administration of security policies, scalability and having a model that follows the organization structure and allows fine-grained access control. Thus in our example, a nurse would be a member of the group of nurses of a certain hospital and would thus have access to certain resources assigned to the role "Nurse".

The exchange of medical information is traditionally ruled by strict sharing policies to protect the patient's privacy but these rules may face exceptions in particular situations (e.g. in an emergency case) [5], evolve over time (e.g. depending on the patient's treatment) and be subject to provisional authorizations [12]. Our proposition aims to provide a balance between strict security procedures and other procedures that break the rules ensuring that there are each case would have a justified context and that ours is where alternative solutions exist and could help in preserving the patient's privacy and the system's integrity.

In fig 3, we present an XML schema of a patient's medical record. Following the XACML RBAC model, if two users (a doctor and a nurse) demand access to this record, the schema will be viewed differently according to the user's role. This is due to the variation of access privileges to the system between a doctor who's allowed to access the whole schema (fig 3) and a nurse who can only view a part of it (fig 4).

As we have discussed, our case concerns a request for consulting a distributed database using a service-oriented architecture and that's where the XACML policy is usually employed for guaranteeing secure and interoperable access. Following the policy's dataflow, the system would evaluate a user's request according to his/her access rights and that's where the access request would be judged to be a **permit**, **deny** or **intermediate**.

Returning to our scenario, supposing that the nurse might request access to the patient's ***Clinical Exam*** in order to evaluate the patient's condition, this request will be verified at a central level of the XACML structure. As we can see in fig 4, the nurse is not authorized to obtain access to the patient's ***Clinical Exam***. Eventually, in this case, the system's ***PDP*** would reply Context Handler's request and would judge the request with a ***Deny***.

The model we're introducing in detail in the next section would provide XACML with a transparent interactive and proactive mechanism. The proposition would enable administrators to anticipate user needs even when they're requesting access to non-authorized parts of a document and would propose some adaptive and alternative solutions to recover the access failure that might occur.

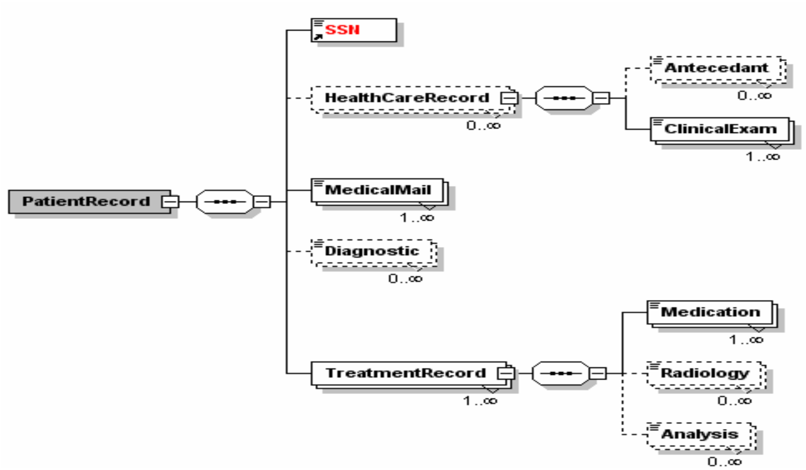

Fig. 3. A simplified XML Schema for a medical patient record (a Doctor's view)

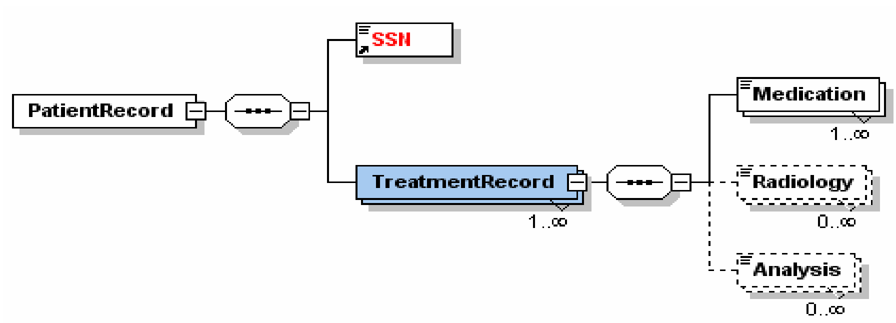

Fig. 4. The authorized part of the patient's record which the nurse can access

6 The MAAC Model: Mutually Adaptive Access Control

As pervasive and ubiquitous environments need special architectures and design [11], we present an adaptive system architecture called MAAC that aims to provide alternative solutions to unauthorized access requests. As we show in fig. 5, our model contains different components and the sequence of its functionality starts from the user, who enters the system by being authenticated (step 1) and then requests access to a certain element (step 2). This request will be interpreted by our ***Query Interpreter*** that will translate the request into an XACML request and would send it to the ***Query Analyzer*** (step3). The request will be analyzed in consideration with the user's profile - that would be automatically produced at the sign in process - and according to his context (XACML flow chart). As the analysis finishes, the Query Analyze would send the result directly to the user if it's a Permit (step 4a) or back to the ***Query Interpreter***, if it's a **deny** (step 4b).

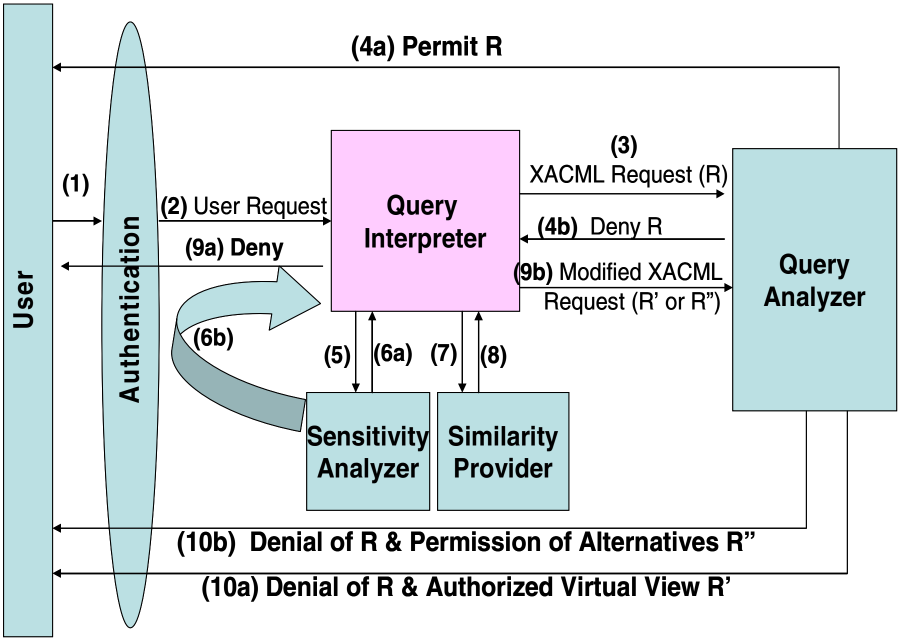

Fig. 5. The MAAC (Mutually Adaptive Access Control) Model

At this step, the adaptive procedure can take place in order to help the user in attaining information that are relevant to their requests instead of responding with an access denied result. Our model helps the user to obtain access to the system but meanwhile enforces some protective procedures in order to be sure that this adaptation wouldn't allow intruders to access undesirable elements. This protective procedure is required after checking the sensitivity of the resource from the ***Sensitivity Analyzer*** (Step 5) which could vary from 0 to 3 and is set explicitly by system administrators at the application side.

So according to the resource's sensitivity, the reaction of the system will change. Starting for example with the sensitivity value that equals to 0 (Sen = 0), the ***Query Interpreter*** would take this result (step 6a) and start a **Virtual View Adaptive Access Control (V-VAAC)** procedure where it would rewrite the user's query using the RBAC model and provide him with a virtual view containing all the elements that he could access in his current context, this modified request **R'** would be sent back to processing by the ***Query Analyzer*** (9b) which would return to the user the denial of the initial request R and the result of the request R' which is a virtual view containing all the authorized elements that the user can access that moment (Step 10a).

Taking the next choice where the sensitivity checked might be equal to 1 (Sen = 1). In this case, the system should be sure of the identity of the user so it will demand from the user to reauthorize himself using a more powerful authentication (Step 6b) and would then proceed making the **V-VAAC** procedure mentioned above.

Assuming that the sensitivity checked equals to 2 (Sen = 2), the ***Query Interpreter*** would take this result (step 6a) and start and would proceed with a **Similarity-based Adaptive Access Control SAAC** procedure. In this procedure, the ***Query Interpreter*** would search for Similarities with the help of the ***Similarity Provider*** (steps 7 and 8) and would use these values to reformulate the user's initial request R to a new request containing these similar elements R". This new request will be also analyzed at the ***Query Analyzer*** (9b) which would finally return to the user the denial of the initial request R and the proposition of providing some alternative solution of the request R" (Step 10b).

Finally, assuming that the sensitivity checked is equal to 3 (Sen = 3), the system will demand from the user to reauthorize himself (Step 6b) and would then proceed making the **SAAC** procedure mentioned above.

Working in the context of semi structured documents, similarity between elements can be added to the system in the form of an XML file created at the application side and would be then provided to the ***Similarity Provider***. In such operation, calculating similarity between elements would enrich the system's semantics.

For each role, we can provide a similarity coefficient between elements so if a system wants to allow strict adaptation, the querying process will check if the demanded resource is allowed and if not, it would try to check the elements having high similarity coefficient.

Adding semantics to the elements of data sources can be performed explicitly by system administrators, data owners or implicitly by using a parser that would compare the structure of the demanded XML file and the other XML documents that are authorized to the user.

For example, consider the case where a nurse has requested to obtain access to the patient's latest medical exam (which doesn't exist in her authorized view). Here, our system would use the nurse's profile containing his/her viewing preferences, current terminal, connection, location, situation and access privileges along with the similarity coefficient between the clinical exam and other relevant elements in order to evaluate his/her request in order to permit or deny her/his access request.

When demanding an unauthorized element, the system would notify the nurse of not having the right to access the demanded element and would respond in one of 2 ways: either a reactive way (**V-VAAC**) by providing the authorized scheme (in a tree format) where the nurse would check whether he/she can access another relevant element or in a proactive way **(SAAC)** by providing her with some elements that she might need by using predefined semantics. As we show in figure 4, our system would propose to the nurse to choose between the authorized elements or would proactively suggest the consultation of the patient's treatment record.

Finally, in order to choose alternative elements instead of the unauthorized requested element, the system would search for relevant element and would check their convenience according a precision degree précised by the administrator, for example it might follow this condition:

If Sim (Patient.Clinical_Exam, Patient.*) ≥ 70% then
    Reformulate **R** by **R"**

The calculation operation can be done at the **Query Interpreter** and thus, the similar elements that are retrieved using this operation will be embedded within the reformulated request R" instead of the originally demanded element.

7 Conclusion

In this paper, we have presented an adaptive solution for healthcare pervasive systems that offers flexible authorization and access in urgent situations. Our solution highlights the importance of using Role Based Access Control for easier distribution of access rights within distributed healthcare systems. In order to accomplish our adaptive vision, we have analyzed the functionality of XACML – a widely used access control policy within service oriented applications – showing that it provides Boolean solutions for access. Thus, our proposition aims to provide users of pervasive services with balanced solutions and adaptive accessibility - based on similarities and semantics - to meet their needs and satisfy the security requirements that the system imposes.

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Patient Sensors: A Data Quality Perspective

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Abstract. Wireless sensor devices with communication capabilities are affected by data quality issues. To ensure that information transmitted by these sensing devices are of a high quality, the data needs to be processed, validated and verified to meet the data quality requirements of the end user. The sensor validation component of the Data Management System (DMS) architecture is presented. It is designed to identify if the real-time sensor is functioning within the correct operating bounds. The DMS is applied within a medical environment to assess its ability to manage real-time patient sensor readings. The effectiveness of the DMS-Validation Model (DMS-VM) is evaluated under two real world scenarios 1) Hardware variance among four Tyndall-DMS-Motes with a patient state of resting and 2) One Tyndall-DMS-Mote under three patient states. The experiments have shown the reliability of the Tyndall-DMS-Mote and the ability of the DMS-VM to ensure sensor data quality. Validating sensor reliability is essential to enable safe remote health monitoring in the home.

Keywords: Data Quality, Patient Vital Sign Sensors, Pervasive Environments, Geriatric Patient Monitoring.

1 Introduction

Poor data quality infrastructures are estimated to cost U.S. businesses more than $600 billion per year. Within a medical environment poorly designed clinical information systems result in inadequate access to electronic patient records. This can contribute to medical errors which may result in patient fatalities. For example according to the Institute of Medicine, 98,000 patients die in U.S. hospitals each year due to poor data management issues. Patient sensors are playing an ever increasing role within medical environments, and these devices can generate large quantities of data. It is necessary to coordinate such data sources to provide the end users (i.e. medical practitioners) with context relevant information. Integration of mobile and sensing devices within a medical environment may provide continuous patient analysis facilities, improved data access and archival data reports. These developments may help to improve the quality of data within clinical information systems.

The issue of establishing a common communication infrastructure/standard between mobile devices and healthcare information systems is still under development [1], [2]. A number of standards have been proposed to assist medical device interoperability

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 54–61, 2008.

(e.g. IEEE 1073) and information interchange (Health Level 7, HL/7). At present such standards are not commonplace across all healthcare environments, due to a lack of vendor support.

Poor data quality stems from a number of factors 1) hardware and software compliance 2) poor business data management practices or 3) failure to fully understand from a semantic or a syntactic view point when dealing with information system results [3].

The DMS architecture [4] is built on a number of components. Each component is designed to process specific data elements to help reduce the potential of poor data quality. During this process it applies relevant data quality checks to ensure that end users receive the correct dataset. An outline is given of the Data Management System-Validation Model (DMS-VM) component and its use in enabling home patient monitoring for the elderly.

1.1 Sensor Validation

The adoption/integration of embedded sensing devices is enabling the next wave of pervasive computing. Within a medical environment, patient sensing devices have the potential to assist medical practitioners. They help elevate the overhead of paper based systems with intelligent sensor based vital-sign recording capabilities. From a data quality perspective the issue of incorrect data entries (i.e. ineligible handwriting (i.e. incorrect datasets) transferred to a database) is reduced.

However a new issue arises in the form of sensor accuracy and reliability. The DMS-VM component of the DMS architecture is designed to validate isolated sensor readings with archival sensor datasets. This helps to highlight potential faulty sensor readings and demonstrate the accuracy and effectiveness of the operating sensors. The DMS-VM is analysed using mobile ECG and pulse sensors under a number of conditions including 1) hardware variance and 2) patient activity.

Alarm or warning mechanisms (with a better safe then sorry logic) are often at risk of being turned off because they become overwhelming and irritating as a vast majority of alarms are raised due to oversensitive rule based mechanisms. This is often seen as getting in the way of the medical practitioners or caregivers task rather than improving their performance [5]. It is therefore important that the sensors integrated within our medical environment, smart home or body area network are validated before higher levels of logic may be applied.

Related work is presented in section 2. The DMS architecture is outlined from a data quality patient sensor perspective in section 3. In section 4 the Tyndall-DMS-mote is evaluated using the DMS-VM component. The delivery of real-time patient information and its ability to reduce false alarm generation is presented in section 5. Finally, a conclusion on the data quality in relation to home patient monitoring is presented in section 6.

2 Related Work

In the USA about 30.3% (10.7 million: 7.8 million women and 2.9 million men) of all non-institutionalised older persons (65+ years of age) in 2006 lived alone [6]. With an expected jump of older persons from 35 million in 2000 to 71.5 million in 2030 the need to provide reliable and functional home care devices is growing. The issues associated with living alone may be compounded if the individual is living in a rural setting cut off from basic amenities (e.g. caregiver, shop).

In the previous decades healthcare information systems have evolved at a steady peace [7]. With the emergence of invasive and non-invasive patient sensing devices the potential for faulty dataset increases. As these datasets are of a critical nature each procedure/process employed to utilise these next generation devices must be performed flawlessly to ensure standards are enforced.

"Sensory readings are inherently unreliable and typically exhibit strong temporal and spatial correlations (within and across different sensing devices). Effective reasoning over such unreliable streams introduces a host of new data management challenges" [8], [9]. In relation to pervasive data quality, sensor validation has a major influence on the delivery of relevant information [10].

3 DMS Architecture and Sensor Quality

The DMS architecture [4] processes the data within its environment from 3 logical layers, Data Collection, Data Correlation and Data Presentation (cf. fig. 1). In this paper the quality of the patient sensor data is examined and evaluated. Patient vital sign readings are captured at the data collection layer and sent to the DMS server for further evaluation. At the data correlation layer the captured patient datasets are evaluated against defined ranges as set by the medical practitioner (e.g. a child resting pulse rate my be set at 70 beats per minute, while a male in his 80s may be set at 90 beats per minute). Other patient information may also be utilised based on their profile (DMS-UP) [11] and medical knowledge base. If a patient sensor reading falls

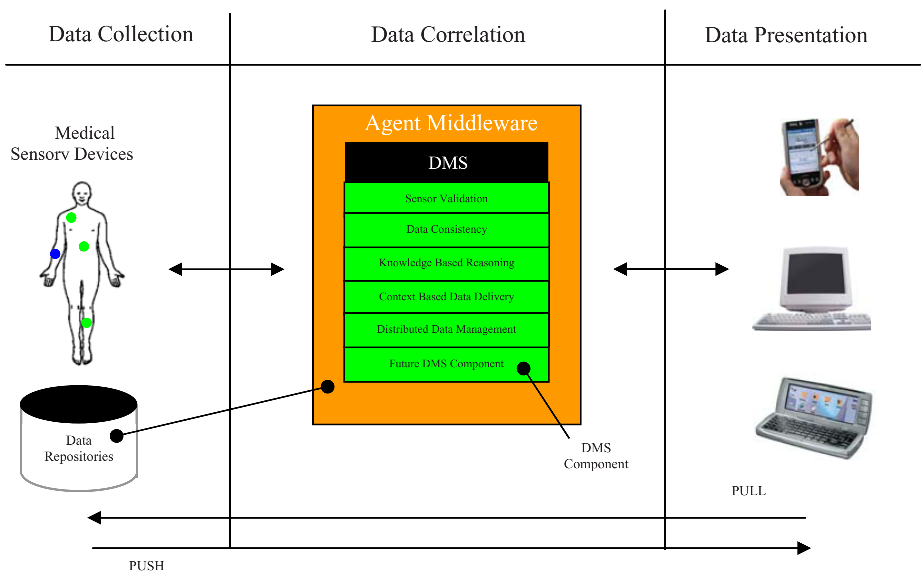

Fig. 1. Patient Sensor: A Data Quality Perspective

outside the predefined operating ranges then the relevant caregiver or medical practitioner is notified at the data presentation layer. Vital sign patient datasets may be pulled by the caregiver upon request or pushed on to their personal computer or mobile device based on a context event which is managed by the underlying agent middleware.

4 Sensor Validation

Pervasive patient sensing devices may generate large quantities of data. This data needs to be transmitted to central medical servers or mobile devices for real-time analysis. Various factors can affect the quality of our patient data. These include: wireless interference (e.g. access point or radio failure) and/or sensor failure. Vital patient datasets may be lost resulting in an incorrect diagnosis.

Patient sensor failure is a reality. It is imperative that sensor failure is detected within a set of real time boundaries. This verified information may then be utilised to assist medical practitioners during diagnosis. The DMS-VM is capable of sampling multiple patient vital sign readings simultaneously. This approach provides a higher data quality infrastructure within a context aware medical environment.

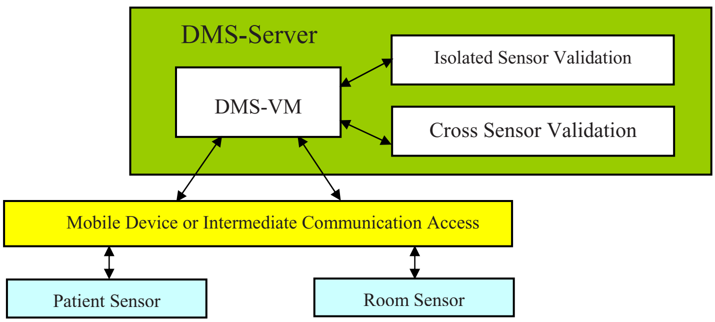

Fig. 2. A Logical Overview of the DMS-VM Component

A logical overview of the DMS-VM architecture is presented (cf. fig. 2) [12]. If a patient monitoring device does not contain sufficient processing capabilities, data is transmitted to a central server. “Isolated sensor validation” may be executed within a single patient mote. “Cross sensor validation” is executed within the DMS-Server and involves more than one device. For example two ECG sensors may be attached to a patient, and the DMS-VM can then determine if the R-R intervals (i.e. period of time between pulse signals) of the sensors are producing similar results.

4.1 Evaluation

An environment or patient sensor is capable of failing and is prone to interference. They are designed to function with built in tolerance levels. The Tyndall-DMS-Mote [13] patient sensor was evaluated against ADInstruments [14] medically certified patient sensing devices (i.e. PowerLab). Presented in fig. 3 is a comparison of four

Tyndall-DMS-Motes with ADInstruments sensors. Motes 1 and 4 achieved an accuracy reading of 100% in comparison with the Power Lab Pulse and ECG. Motes 2 and 3 achieved an accuracy of 99% and 97% respectively.

The Tyndall-DMS-Mote results presented in fig. 3 were generated after passing through the DMS-VM component. Within the DMS-VM component raw patient signals were initially filtered and analysed in isolation. They were then compared with the PowerLab sensors. While in a real world medical environment a patient would not typically have 3 or more sensors of the same type attached, here it is done to provide the basis for direct comparison. The DMS-VM results demonstrate that Tyndall-DMS-Mote patient sensor can operate effectively and produce high quality datasets.

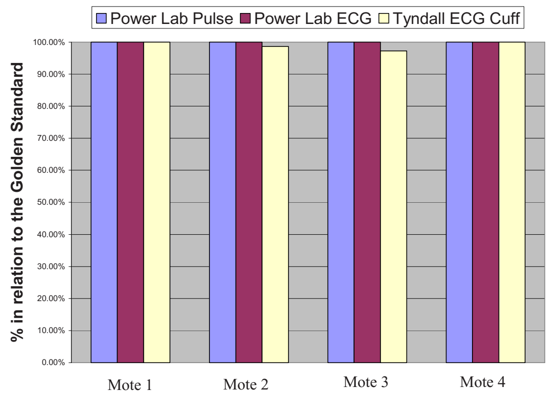

Fig. 3. A Comparison of four Tyndall Patient Motes with a patient state of resting. The golden standard is the known beats per minute.

Fig. 4. Three patient states, Resting, Running and Running to Resting. The golden standard is the known beats per minute.

The manner in which a patient's vital signs are recorded can greatly affect the overall accuracy. An ECG recording is extremely susceptible to external interference. A patient's movement during a recording can interfere with the final sensor reading. The Power Lab and Tyndall-DMS-Mote sensors are designed to record ECG and pulse signals while the patient is in an idle state. Presented in fig. 4 is an overview of how the three sensors sampled their respective signals. The running state was recorded immediately after the patient stopped running.

The Tyndall-DMS-Mote in comparison with ADInstruments medically certified patient sensing devices has been shown to provide correct patient readings with a high degree of accuracy. The Tyndall-DMS-Mote allied with the DMS-VM has been demonstrated to maintain this required standard with little to no loss of vital patient datasets.

5 Data Delivery

Reacting to a sensor failure in real-time can greatly enhance the overall reliability and dependability of a system. Within a pervasive environment, sensor validation is one process which can help deliver high quality data to the end user. Fig. 5 and 6 represent data delivered to a medical practitioner's PDA. It contains specific patient details with recorded and real-time pulse sensor readings. All sensor readings displayed in fig. 5 represent valid BPM readings, i.e. readings which reach a DMS accuracy level at a minimum of 95%. The average accuracy of the two Power Lab Sensors and the Tyndall-DMS-Mote ECG is identified as 99.48% for this recorded period of two minutes. Fig. 6 highlights a scenario where a sensor has not reached the desired level of operation. This is visually represented as a red background to alert the medical practitioner or caregiver of this fault or error. It is important to note that the two Power Lab sensors reached a level of 100% accuracy. With this in mind the medical practitioner may decide to accept the sensor readings and alert relevant technicians of the Tyndall-DMS-Mote sensor failure. This approach helps to identify faulty sensors within the environment thus improving the overall quality of service and patient care.

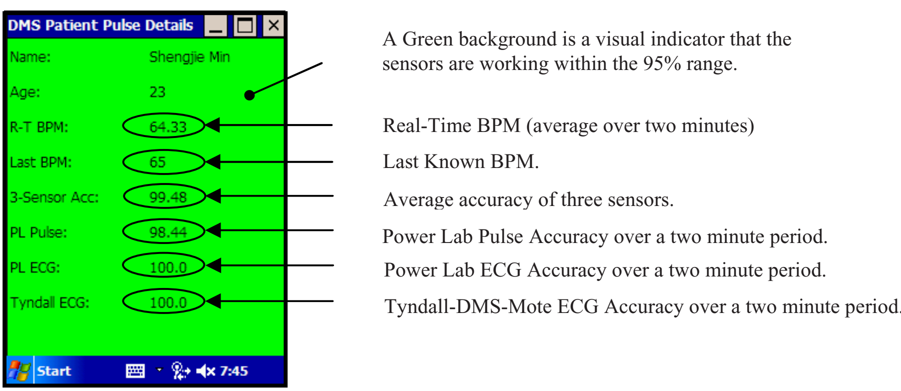

Fig. 5. Three valid patient pulse readings

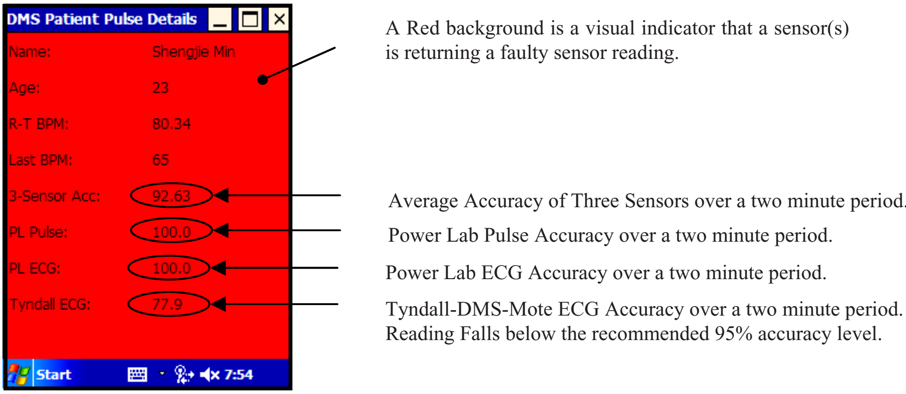

Fig. 6. Two valid pulse readings and one poor pulse reading

6 Conclusion

Presented is the DMS architecture and its ability to enforce data quality constraints through the DMS-Validation Model. Careful experiments with a patient sensor have been used to demonstrate the capabilities of the DMS-VM.

The DMS-VM component is designed to validate real-time patient sensor readings. As sensor failures occur, early detection is paramount. A key issue with automated error detection systems are the number of false alarms generated based on incorrect information. This may result in poor dependability and usefulness. The DMS-VM component is capable of validating sensor readings in isolation or in comparison with similar data producing sensors. The primary benefit of the DMS-VM stems from the quality of the readings presented to the medical practitioner. The experiments have shown the accuracy of the Tyndall-DMS-Mote and the ability of the DMS-VM to ensure quality of sensor data. The use of these devices for patient monitoring can greatly enhance the quality of patient care, for example as might be used for remote elderly individuals.

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Design of a Smart Continence Management System Based on Initial User Requirement Assessment

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Abstract. Those with dementia need closer attention and monitoring when they develop incontinence. Incontinence can lead to medical complications such as skin breakdown, places greater demands on caregivers, and strips the patients of their dignity. We have taken a step towards building a smart continence management system (SCMS) by automating the detection of events and forwarding details of these events to caregivers. Besides reducing bedsores and concomitant ill-effects of the elderly remaining in soiled diapers for prolonged periods, SCMS also benefits caregivers, helping them improve visitation schedules and time management. In the *user-requirements generation* phase, a cohort of people were interviewed. Subsequently the user-requirements were translated into *technical specifications,* based on which, a product survey was conducted. The system was designed, implemented, deployed and is being evaluated at a nursing home in Singapore. Initial results are encouraging. A planned *usability study/overall system evaluation* will provide new requirements for the second version.

Keywords: Continence Management System, Dementia Patients, Wireless Sensor Networks.

1 Introduction and Rationale

Urinary incontinence affects people of all ages and may be acute or chronic. Incontinence frequently accompanies cognitive failure and typically appears in the mid- and late-phases of a dementing illness. The condition is distressing to caregivers, undignified for patients (who sadly often posses limited awareness), and is a major factor when one considers the need for institutionalization. The paper presents a study

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 62–72, 2008.

investigating automated means to respond to the need for diaper change, amongst elderly people with dementia.

The key problem we are aiming to address is delay in responding to the need for diaper change following an episode of urinary or fecal incontinence – leading to the situation where the patient with dementia lies in soiled diapers for a long period, leading to discomfort, anxiety, distress, and possibly skin breakdown and bedsores. The current practice involves the caregiver having to conduct periodic checks leading to unnecessary visits and/or delayed response. In this paper a new method involving an automated means of alerting the caregiver thereby leading to greater patient relief and fewer demands made on the caregiver's time is presented.

Studies previously undertaken [1] indicate that caregivers' visits to check if the diapers are soiled can be reduced by as much as 50% through the use of an automated ICT-based service. The magnitude of the problem is immense. For example, in the UK, around 3 million people and some 60% of nursing home residents suffer from urinary incontinence. This equates to around 5% of the population. The National Health Service (NHS) in the UK spends an estimated $283M million per year on incontinence products, e.g. absorbent padding, with the total cost of dealing with incontinence around $992 million, (which is 1% of the NHS budget). The long term costs are set to rise as the majority of European and other developed economies experience demographic forces that result in a growing elderly population that lives longer, placing additional stresses on community and healthcare budgets. A major theme of UK's Technology for Independent Living conference in 2004, was the acknowledgement that current technologies for treating and managing incontinence have several limitations and that there is an urgent requirement of new methodologies and need for innovative new thinking.

The objectives for the smart continence management system are i) to develop an unobtrusive and easy-to-use wetness alert sensor assembly to be deployed in diapers for people with dementia; ii) develop an event detection and alerting forwarding system that is capable of informing caregivers of the need for a diaper change; and iii) evaluate the impact of the diaper/event forwarding system in a pilot trial consisting of a number of patients and their caregivers. Version one of the SCMS will focus mainly on nursing home deployment with version two being targeted at other types of home and hospital based deployments.

This paper presents details of the four phases of the first version of the SCMS. Section 2 discusses the *user-requirements generation* in which we collected responses to questionnaires and undertook site visits, focus group discussions and interviews with medical professionals and caregivers, in order to quantify end-user needs and requirements for SCMS. Section 3 presents the *technical specifications* where existing products were studied to find the limitations and desirable features for the proposed system. Section 4 presents the *design and development* of a smart continence management system. A trial is currently being conducted in a nursing home, to evaluate the solution. It is planned that the trial will be extended to another nursing home. Section 5 outlines the *planned usability study/overall system evaluation* of version one, where we will evaluate the effectiveness and usefulness of the system as a means to generate requirements for the next version of SCMS. Section 6 concludes with discussions of future work.

2 Questionnaire Survey

The initial stage of elicitation of user needs was based on a series of questionnaires. In the first instance these were targeted at caregivers with the intention of assessing their views on the issue of continence management. It was explained to the caregivers that the purpose of the questionnaire survey was to investigate their views on the needs to perform diaper change within a timely manner. We explained that we intended to do this by determining if the patients had soiled diapers for long periods of time, since this could lead to sores and other complications. We further explained that our proposed system would send out a signal to the caregiver once the diaper was wet, thereby ensuring timely change. Table 1. presents the questions asked in the survey form.

In addition to the above questions, the caregivers were also asked how frequently they checked for soiled diapers, i.e. every two hours, four hours, six hours or as and when needed (randomly). Two groups of questionnaire responses were collected. Group A consisted of staff from two nursing homes in Singapore and Group B consisted of staff from a single elderly care institution in Taiwan, where the average age of its 100 residents is about 87. Most of the residents in all these institutions are on wheelchairs and need help in carrying out their ADLs. In Group B, among the 30 respondents 7 of them have nursing licenses in addition to having training in taking care of the elderly; whereas the remaining 23 respondents are trained professional caregivers for the elderly. The responses to the questionnaires were obtained over a two week period for Group A and one day for Group B.

In Group A, the results of the survey overwhelmingly indicated the need for the SCMS. Out of 44 respondents, 42 responded with "Agree" to all of the questions. Only two respondents felt that they would not save time by cutting down on unnecessary checks, since they followed a schedule in which they routinely carried out checks every three or four hours. Group B exhibited greater diversity in their responses. Approximately 43% felt that they disagree that timely change of diapers was difficult to achieve and about half disagreed that time could be saved by cutting down on unnecessary checks. The reason for this could be the high frequency at which checks are made by this group (27 of the 30 respondents in this group indicated that they carry out checks every two hours). For the remaining questions, i.e. questions 2, 4, 5 and 6 the responses from both groups were quite similar. Thus overall it can be said that the need for SCMS is quite well justified as a result of this questionnaire survey.

In addition to these questionnaires, we conducted focus group sessions with hospital and nursing home staff and caregivers on four occasions to analyze requirements in terms of the factors to be considered in an automated wetness detecting system.

2.1 Requirements Analysis – The Healthcare Viewpoint

The following can be considered as the most important factors when considering the use of wetness sensors from the end user's perspective.

Sensor Type. There is a strong objection to the use of products that have a wired connection attached to the patient since it affects the safety, comfort and in some instances the mobility of the patient under surveillance.

Table 1. Questions asked in the survey form and survey results

	Question	Dis-agree	Some-what disagree	Un-sure	Some-what agree	Agree
1	Timely change of diapers is important but can be difficult to achieve.	A: 0 B: 9 T: 9	A: 0 B: 4 T: 4	A: 0 B: 2 T: 2	A: 0 B: 8 T: 8	A: 44 B: 7 T: 51
2	Patients, especially those with aphasia and advanced dementia, may lie in soiled diapers for prolonged periods without caregivers knowing.	A: 0 B: 1 T: 1	A: 0 B: 2 T: 2	A: 0 B: 3 T: 3	A: 0 B: 11 T: 11	A: 44 B: 13 T: 57
3	Time can be saved by cutting down on unnecessary checks to determine if the diaper is soiled.	A: 2 B: 10 T: 12	A: 0 B: 4 T: 4	A: 0 B: 1 T: 1	A: 0 B: 1 T: 1	A: 42 B: 14 T: 56
4	Diaper dermatitis and bedsores are common and important problems related to diaper usage.	A: 0 B: 0 T: 0	A: 0 B: 0 T: 0	A: 0 B: 0 T: 0	A: 0 B: 3 T: 3	A: 44 B: 27 T: 71
5	It is unhygienic and undignified for a patient to lie for prolonged periods in soiled diapers.	A: 0 B: 0 T: 0	A: 0 B: 0 T: 0	A: 0 B: 0 T: 0	A: 0 B: 1 T: 1	A: 44 B: 29 T: 73
6	I would value much any intervention to enable timely diaper change so as to reduce diaper dermatitis/bedsores.	A: 0 B: 0 T: 0	A: 0 B: 0 T: 0	A: 0 B: 2 T: 2	A: 0 B: 1 T: 1	A: 44 B: 26 T: 70

Sensor Size/Dimension. Bulky sensors attached to the diaper are not desirable. The sensing component needs to be as small and thin as possible (e.g. like RFID tags).

Sensor Reuse. The reusability of the sensor component causes extra work, since the sensors have to be taken out from the wet diapers, cleaned of urine or feces, dried, and put back into a new diaper. A disposable diaper integrated with a disposable wetness sensor is highly desirable.

Cost. Cost issues are quite complicated. The incremental cost of a single diaper should be viewed against the overall saving in terms of patient safety and comfort, and caregiver relief. As presented in [1], detailed cost analysis in trying to address this problem is multifactorial and also largely dependent upon the underlying regional healthcare model. Nevertheless, the work presented in [1] has only addressed the problem for a portion of Europe, hence a similar study is required to address the Asian and American contexts, since the model for delivery of care for the elderly is very different.

Safety. The use of Radio Frequency (RF) signals should conform to the standards required by the medical environment. All products studied by us use the 400 MHz ISM band which is free for use (unlicensed). Needless to say, the equipment should not harm the patient in case of malfunctions or errors, since the sensor unit is attached to diaper that is worn by the patient at all times.

3 Product Survey and Related Work

3.1 Requirement Analysis – The IT Viewpoint

In order to develop a customizable wetness sensor, we examined the desirable features of sensors to be developed as well as possible extensions to existing products. The following requirements were therefore identified.

Expandable and Extensible System. Wetness monitoring of the elderly should be properly handled by sensing unit regardless of the patient location for example on the bed or in a wheelchair. Multiple diaper units should be able to operate within the same environment concurrently and should be easily controlled by a centralized system. There should be an easily configured infrastructure as well as intelligent signal relay network to use together with other healthcare applications.

Coverage Area. The coverage of the monitoring area should reach the entire ward or nursing home where the patient is likely to be present. It should use standard wireless communication protocols such as Zigbee, Bluetooth, etc to extend the coverage area limited by proprietary wetness sensors. It is important to note that the underlying technologies should be compliant with existing rules and regulations adopted in medical environments.

Personalized Intervention. The alerts and interventions should operate according to the user's personal preference. Use should be made of commonly available everyday technologies (such as SMS, flashing light, email etc.) to forward the events to the relevant parties.

After considering both the medical and technical requirements, we found two products (highlighted in Table 2) that were easily extensible and could be integrated with external components. Moreover, the technical documentation which was available was complete and the components were deemed easy to manipulate. The requirements of full wireless connectivity and flexible customization and integration with external wireless platform, however, left only one product suitable for our use to develop the wetness alert diaper.

Products for children and adults [3, 4, 5] in the market are mainly aimed at toilet training i.e. for children to help them gain control of their bladder. For example, Malem Medical offer a range of Enuresis alarm products [3]. With these products the sensor is connected through a wire to a separate transmitter which is clipped onto the pyjama top. The receiver provides a sound, vibration or flashing light alarm upon a wet episode. The receiver alarm can be placed up to 25 meters away from the patient hence it does not need to be in the same room. Although specifically designed for Enuresis treatment i.e., behavioral change in bed wetting (with the purpose of the alarm wakening a child upon bed wetting) it could be used for incontinence where a caregiver could check the receiver for a flashing light without specifically waking/disturbing the patient. Enurad® 400 provides a compact wireless wet-sensor with a built-in radio transmitter [4]. It is specifically for treating Enuresis in children where the sensor triggers an alarm clock (up to 6 meters away) to wake the child upon a wet episode.

3.2 Related Work in Automation of Continence Management through Alerts

There has been some prior work conducted in the area of Continence Management (CM) through wetness sensors and alerts. This can be categorized into efforts that deal with children and those that deal with adults and elderly. Most of the products in the market fall into the first category, and are aimed at toilet training children to help them gain control of their bladder (as mentioned in the previous Section). Nevertheless, there has been little work reported in the area of continence management systems for dementia patients, either to alleviate patient / caregiver problems, or to mitigate the problem through controlled voiding.

Table 2. Continence Management Products

Sensor Model	Communication	Equipment	Remarks
Wetix 102	Wireless	Sensor (2x1x0.5 in) Receiver (3.5x2.6x1.1 in) Sensor Pockets	Sensor is bulky inside pants
ENURAD 400	Wireless	Moisture Sensor (60x25x6 mm) Clock Alarm	Incomplete documentation and information about product and usage
Dri-sleeper Eclipse	**Wireless**	**Uro Sensor(50x25x6 mm)** **Alarm Unit (80x40x20 mm)**	
Dri-sleeper Excel	Wired	Uro Sensor Alarm Unit (60x40x15 mm)	
Malem Wireless M07 Model	**Wired and Wireless**	**Transmitter (56x51x17 mm)** **Receiver (150x85x36 mm)** **Easy Clip or Standard Sensor** **Bedmat sensor**	**Not completely wireless solution. Wireless interface between Tx & Rx but Wired interface between Tx & Sensor**
Wetstop-2	Wired	Wetstop Sensor Alarm	Wired connection between sensors and Tx.
Wetstop Wireless	Wireless	Wireless Sensor (1.5 in dia:) Receiver & Alarm Unit	
Nite Train-r alarm	Wired	Wired Sensor(2.7x6.6x0.1 in) Alarm Box (2x2.5x0.8 in) Sensor Wire (25 in long)	Sensor is too big and differentiation between genders.
Nite Train-r wet call	Wired	Sensing Pad(18.5x24.5 in) Alarm Box Conducting Cord(66 in long)	Sensor is not attached to patient and used as a bed sheet.
Nytone	Wired	Sensor (2 x 0.5 x 0.5 inches) Wrist Alarm (2.25 x 2.5 x 1.5 inches)	Patient needs to wear wrist
Rodger Wireless Alarm	Wireless	Alarm Transmitter(1.5x1.5x0.6 in) Alarm Receiver (2.5x4x2.5 in) 2 special briefs for Transmitter Attachment Rodger brief	Requires Special Briefs
Potty Pager		All-in-one pager	Whole equipment is attached to patient's pant. Requires specific briefs.

A limited amount of work has been presented in the research community related to sensors for urine detection. The Robotics Institute from Carnegie Mellon University have proposed a low-cost odor-based sensor [6] to monitor incontinence while researchers from Tokyo Medical and Dental University [7] have proposed a system based on the principles of temperature and impedance changes to detect urine. Recent work by [8] describes the use of an energy harvesting method with new smart RFID technology called Action Activated Tag (AAT) to develop a disposable wireless diaper unit.

However, concrete proof of the effectiveness of most of the above systems for continence management in the real world and clinical setting is lacking. There is a lack of understanding of the workflows involved in the management of continence among large patient groups in such settings, and a lack of understanding of which types of sensors and reminders might be the most effective for continence management. Furthermore it is not easy to conduct rigorous clinical trials to study usability of the systems from both the human and technology perspectives. Much collaboration and understanding is needed between clinicians and engineers to organize such a trial and herein lies the value of the trial we are conducting.

4 Design and Deployment of a Smart Continence Management System

After numerous discussions with doctors, caregivers and nursing staff at hospitals and nursing homes we iteratively designed the SCMS, taking into consideration both the needs of the patients and their caregivers. Cost was also an important factor which was inherent in decision making during the design and development stages. The system which was finally deployed is depicted in Fig 1. This solution is capable of monitoring several persons simultaneously, given that they are located in the same local area for example within as in a nursing home or a similar care facility. The patient may be in bed or in a wheelchair. Smooth transition in terms of the person moving from the bed to the wheelchair and back again is important. For this reason we have had to modify an earlier design which called for the caregiver to remember to physically remove the receiver unit from the bedside and mount it on the wheelchair. This called for additional work to be performed by the caregiver which was deemed to be an undesirable departure from their normal duties.

In the current deployment a separate receiver unit is therefore permanently attached to the wheelchair. Given that the type of sensor we are using is of the non-disposable type, there is at present a requirement that it should be washed and re-used. Once again this introduces work which is outside of the normal duties of the caregiver. For this reason (and only for the initial trials) we decided to have additional units of new sensors ready for use in case a diaper needs to be replaced. The cleaning and recycling of sensors from soiled diapers then becomes a batch operation which can be scheduled and performed offline – at a convenient time.

Fig 2. shows the various system components and the relationships among them. The first component is the *sensor unit* (Fig. 2 (a)), which is composed of the wetness

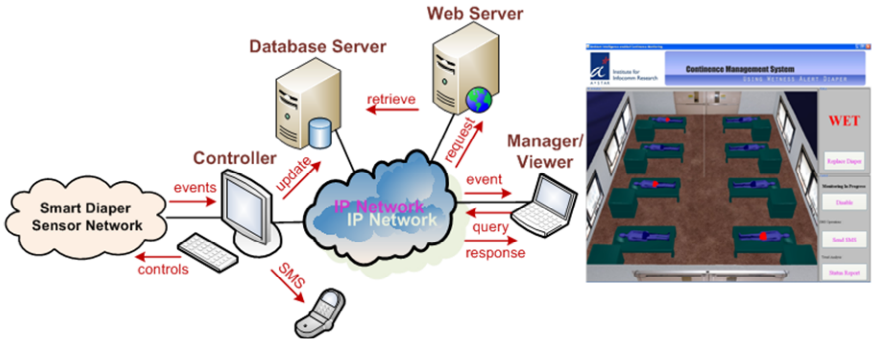

Fig. 1. Architecture and GUI of Smart Continence Management

sensor and transmitter pair coupled with the wireless communication facility. Its main tasks are to detect wetness in the diaper and subsequently report the detected event. The second component (Fig. 2 (b)) the *intelligence unit* is built by integrating the diaper receiver unit and the alert system with the sensor node, which is mounted on the micaZ mote [9] wireless sensor network platform. Its main function is to capture wetness events and to receive control events (messages), to take decisions on incontinence status, activating the integrated optional alert system as needed, and managing devices and disseminating the events to other units wirelessly. The third component is the *relay unit* (Fig. 2 (c)), which is composed of the primary alert system integrated within it. Its main functions are to relay messages between the intelligence and the service units; and to activate the alert system upon receiving notification requests to notify caregivers. The final component as shown in Fig. 2 (d) is the *service unit* which consists of a wireless gateway, an SMS gateway and a server. This provides a user-friendly GUI to manage and provide continence care, SMS alert services and a web-based manager and viewer applications for handling incontinence.

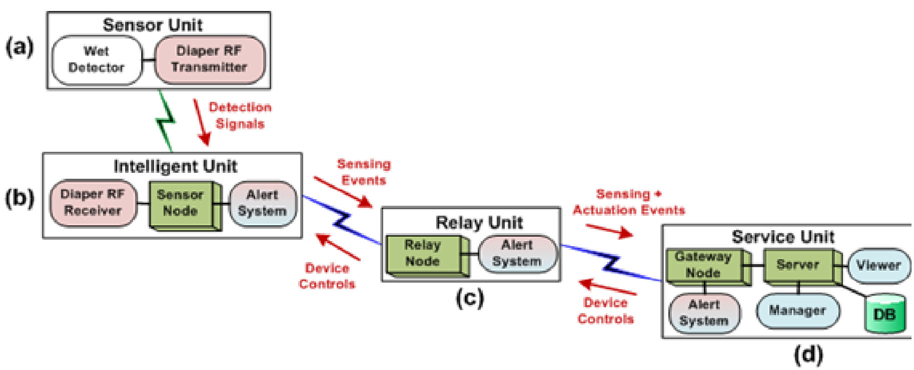

Fig. 2. Various System Components (a) Sensor Unit (b) Intelligent Unit (c) Relay Unit (d) Service Unit

5 Planned Usability Study and Evaluation of Outcomes

The currently deployed SCMS will be enhanced for the second version of the deployment when a much larger trial is envisaged. For remote access, a secure website will be established that will allow staff members to access the information from the trial deployment as required. The initial information will provide a daily summary for each of the subjects showing the number of wetness episodes, their frequency, the response time in each case, correlation with meal / beverage time and other related captured information.

Fig. 3. SCMS deployment at Nursing Home: (a) Gateway Node (Service Unit) (b) Relay/Actuator Node (Relay Unit) (c) Top: Wetness Sensor (Sensor Unit) and Diaper Node (Intelligent Unit), Bottom: UI System (Service Unit)

The subjects and caregivers will be surveyed prior to the trial to determine a normal day's routine for both subject and caregiver. This will be achieved through informal and structured interview techniques using established bladder chart and toileting scales. Repeat interviews will be undertaken to validate information collected and to check for reasons for anomalies. Demographic, health and other information about the patients will be obtained from the hospital, and whatever is unavailable will be obtained from the survey. Relatives and caregivers will be interviewed in order to determine the best form of delivery of alerts and notifications (e.g., cell phone, pager, PDA, email) thus a variety of "reporting" formats will be developed and evaluated. In addition at a later stage, we plan to include geriatric service managers, social services support staff and members of the extended family network.

The evaluation of the usefulness and efficacy will be based on qualitative interview techniques and completion of standard continence charts/bladder scales as well as via reference to sensor-based algorithmic data. The anticipated outcomes from the trial are detailed use case study materials leading to functional specifications based on consultation with doctors and caregivers, encompassing the validation of specifications with patient histories (with participation of doctors), trial study results using the system by selected patients in their homes, fine tuning of algorithms, validation of results and finally evaluation and assessment.

Based upon the research questions and the desired outcomes the sample size has to be chosen appropriately. For example to establish caregiver acceptability of the SCMS concept, the sample size for administering the pre- and post- questionnaires need not be too large. Nevertheless, to establish that SCMS helps in reducing diaper dermatitis the sample size would need to be much larger. Ten patients with dementia and their caregivers will therefore be recruited in this stage of the study. Dementia will be diagnosed according to DSM IV criteria [10]. The included patients must have established urinary and/or bowel incontinence requiring the use of diapers. There must be a caregiver who is available and who is able to provide around the clock care for the patient. Patients who are acutely ill with unstable vital parameters, with pacemakers and implantable defibrillators or who exhibit effects of specific medical or medication related causes of incontinence will be excluded from this study.

6 Possible Future Directions and Conclusions

To develop a low cost disposable wetness alert product is a clearly identified problem. Nevertheless, there is a lack of evidence in relation to the impact of such a solution for those suffering from Dementia and as such detailed tests should be conducted to determine the most acceptable placement for both the sensor and the antenna, before embarking on a disposable version of the current prototype. In this paper we have presented the methodology adopted for carrying out an end- user oriented design and deployment of a continence management system based on the notion of automated wetness detection. The project was planned in two stages, each stage consisting of a user needs analysis, a technology survey phase (if required), a design and deployment phase and finally an evaluation phase. The evaluation phase of the first stage will produce the necessary direction required to refine the system for the ensuing stage of evaluation.

There are a number of areas within which we have identified potential for further work. Odor sensor integration is a possible direction too, since this will enhance the detection accuracy of fecal incontinence. Efforts are also currently under way to standardize the gateway to platform interface to various types of wireless sensor platforms. Machine learning algorithms can be put in place to identify patterns of diaper wetting episodes. This will lead to effective training of voiding behavior (as in the case of children), thus possibly even diminishing the continence problem. Placement on bed-mats rather than diapers is another possibility and will address a sizeable percentage of the incontinence problem (both dementia and non-dementia related). Technically the solution will not be very different, and possibly easier.

The current system is a "push" based system – i.e. it pushes events to the clients. There is also a need for a "pull" based system – whereby a caregiver can query the system to find out if there is an episode of wetness among the patients. This approach can be used to assist with the notion of appropriate planning of visits. We intend to add this pull functionality to the system in the future. Finally, work needs to be undertaken in the area of personalization of the system and its interfaces for different categories of end users according to their roles. The above-mentioned points will be addressed as our future work in this project.

Acknowledgements

This work was supported in part by Alzheimer's Association through Everyday Technology for Alzheimer's Care (ETAC) grants. We would like to thank the staff of Alexandra Hospital (Singapore), St. Joseph's nursing Home (Singapore), Villa Francis Nursing Home (Singapore) and POTZ Hospital (Taiwan), for their useful suggestions and their responses to the questionnaire. Some work in University of Ulster was supported by Investment Belfast 25K Award, 2004.

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Social Rhythms and Nocturnal Routines in Community Dwelling Older Adults

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Abstract. This paper describes a pilot carried out by The Digital Health Group in Intel, in which daily social rhythms of community dwelling older adults were examined and related to objectively and subjectively recorded sleep measurements. Ten relatively healthy independently living older adults were interviewed using ethnographic processes to determine a baseline of social activities, behaviours and nocturnal sleeping routines. Each home was fitted with six sensing elements to establish and monitor daily and nocturnal activities. Sociality behaviours were explored through social contact through phone conversation and human interaction, through mobility, inside and outside the home, and through a person's self reported internal state (how they feel each day). Nocturnal rhythms were examined through actigraph watches and bed pressure sensing devices. A preliminary sub set of the results are presented in this paper in the form of case studies showing subjective and objective data sets and their comparison to social routines.

1 Introduction

"*Sleep is a pillar of a healthy lifestyle. The magnitude of its effect on health is likely similar to the effects of diet and exercise"* Najib Aayas, MD, Assistant professor of Medicine, University of British Columbia School of Medicine in Vancouver, British Columbia, Canada.

Typically the total sleep time during the night is reduced in the elderly. Elderly people tend to fall asleep earlier and wake up earlier with more frequent awakenings during the night. Older people frequently complain of longer sleep latency, frequent awakenings at night, insufficient sleep time and daytime sleepiness [1]. Whilst some have pointed out the links between sleep disturbance in older people and the

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S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 73–80, 2008.

deterioration of the circadian timing system [2] there is a growing body of research that suggests that this is not an inevitable consequence of ageing but should be considered in relation to a range of factors including life events, chronic disease, physical disability, depression, widowhood, medication, and social activity. The argument that many of the health changes in later life, including the decline in sleep and cognitive abilities, can be minimized by avoidance of social isolation and disengagement is supported by Benloucif et al. [3]. Foley et al. [4] concluded from the 2003 Sleep in America Poll that sleep complaints are not the result of normal ageing and proposed that they are often secondary to chronic disease. Chasen et al. [5] concluded their study suggesting that sleepiness (derived through telephone interviewing based surveying) may be as important as body weight in predicting whether older adults exercise, this is especially important because exercise and physical activity promote healthy ageing and can reduce or prevent functional declines that are associated with ageing. Gooneratne et al. [6] used the Functional Outcomes of Sleep Questionnaire to measure functional areas sensitive to sleep disturbances in adults. They found that sleepiness had a moderate to large negative effect size on the following domains of the scale: social outcomes = 0.65; general productivity = 0.59; vigilance = 0.75; and activity level = 0.83 (all P values < 0.005) The objective of this study was to examine the sleeping patterns amongst a preliminary sample of ten older adults as they followed their usual schedule of activities, rest and sleep throughout the day recorded both objectively and subjectively with an aim to establish the relevance between social activities and sleeping behaviour. We proposed to examine daily routines and extract how they are influenced by sleeping patterns and visa versa with particular emphasis on social behaviour.

2 Daily Activity Monitoring

To examine daily sociality behaviours and routines, sensing elements were placed in the homes and cars of participants for a two week period between June and July 2007 to automatically monitor sleep, social and physical activity. These included landline telephone logging devices, which monitored time, direction and duration of each call. Mobility was monitored both inside and outside the home with the use of pedometers and personal and automobile GPS devices. Daily morning and evening diaries were carried out by the participant through digital audio recorders. These diary entries consisted of a suitably modified version of the Pittsburg sleep diary to allow manual twice daily logging of relevant data, in an audio form, following procedures developed for the qualitative study of sleep by Hislop et al. [7]. The person's self reported internal state (how they feel each day) was also recorded daily. A Tactex BEDsensor™ under mattress bed pressure sensor was placed underneath the mattress of each participant for the duration of the study. A pre and post study ethnographic interview was held with each participant to establish routine behaviours and used to validate discrepancies in sensor data.

2.1 Evaluation of Sensor Data

Rather than extracting a quality of sleep parameter sleep quality was examined through regularity of bedtime routines and establishing baseline behaviours. The primary patterns looked for were: Bed Entry and Exit Times, Time in Bed, Bed Exits during the night and their duration, restlessness patterns, established through an index of restlessness and percentage of restlessness measures. The sleep data was correlated and extracted using a Tactex BEDsensor™, under mattress bed pressure sensor. The Tactex bed sensor permits 24-hour monitoring of sleep whenever subjects are in bed. The sensor data is autonomously logged through a PDA (Dell Axim x51v), which is stored underneath the bed. Internight variability among participants was examined in terms of the sleep related to social routines. Within sleep studies TIB refers to nocturnal Time In Bed (the TIB encompassing the main sleep period of the day, initial bed entry to morning arising). Average nightly TIB for healthy adults has fallen form approximately 9 hours in 1910 to 7 hours in 2002 [8]. Prinz's et al. studies on sleep monitoring of elderly individuals have shown average nocturnal TIB of 475.6min (+-52 min) [9], Feinberg et. al showed it to be 468.9min (+-38.3) [10]. Within this study the intrasubject TIB ranged from 7.67 – 9.61 hours (460.2 – 576.6 mins) with a standard deviation ranging from 0.52 to 1.24 hours (31.2 -74.4mins). The mean TIB within the study was 524.4 mins +- 40.8mins for all ten participants. The general regularity of sleeping patterns may be due to their general health as the participants are individuals who are successfully living independently. Those with greater health problems, which are associated with deteriorating sleep patterns, should be expected to have a diminished competence for self-sufficient living and be more likely to move in with family members for assisted care [11]. Duncan et al. [12] suggested that community living elderly were more regular in their life-style behaviours than a control group of younger persons. It is possible that such consistency in their daily schedules may be functional by facilitating the preservation of sleep patterns that the ageing process and physical problems can disrupt [11].

2.2 Actigraphy and Restlessness Monitoring

Actigraphy is used for home monitoring of regularity of sleeping patterns within individuals without disturbing ordinary everyday life. Actigraphy provides useful measures of sleep-wake schedules and sleep quality. The twenty-four sensor outputs on the Tactex BEDsensor™ show the distribution of weight across the array. Each sensor outputs a signal that is correlated to the applied pressure but is not an absolute measure of pressure. The output from a single sensor is a combination of mean weight, movement weight, and noise. Movements originate from conscious muscular movement, such as raising an arm or turning over and autonomic bodily movements such as cardiac and respiratory function. Using the Tactex BEDsensor™ data muscular movements are identified and classified according to severity. The raw data from the Tactex BEDsensor™ is first interpolated to ensure accurate sampling. The data is then sampled over 30 second Epochs. The first step to extract motion was to calculate a moving variance for each individual sensor for each epoch. If the variance for an individual sensor exceeds a thresholded numerical value the movement count for that epoch is incremented. The threshold was empirically derived depending on the individual environment conditions based on the thickness of the individuals mattress; if the movement count exceed a critical value the epoch was considered an epoch of movement. A minimum amount of sensors must exceed the threshold for that epoch to be considered a movement epoch. The movement count value was used to classify each epoch based on the movement severity. The actigraphy values were used to represent an index of restlessness, which was used to rank the individuals quality of sleep. The percentage of movements during the night was used as an indicator of the quality of sleep, whereas consistency of patterns may be used to determine if there are changes in the subjects overall sleep patterns. Figure 1 shows a two weeks representation of the output window of the sleep parameters extracted.

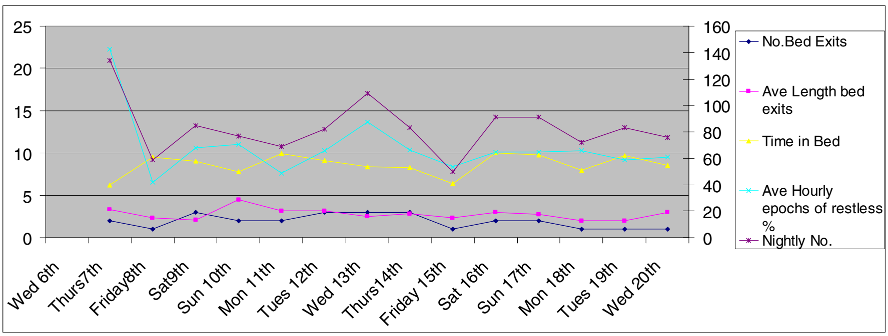

Fig. 1. One weeks Sleeping Patterns extracted from the Tactex BEDsensor™

2.3 Social Activity Monitoring Index

The Social Rhythm Metric (SRM; [13]) quantifies the stability of an individuals daily routine. It lists 17 activities that have been identified as central in everyday life and leaves space for two more optional activities for the individual. The SRM is meant to be completed every day, with subjects writing down the exact time of the beginning of an activity. A short version of the SRM was proposed by [14], where only five activities (get out of bed, first communication, start work, have dinner, go to bed) are considered. As two of the five activities are related to sleep–wake patterns ("get out of bed" and "go to bed"), this short version of the SRM emphasizes the sleep–wake cycle as a major anchor in the daily social rhythm. The SRM has been described as a valid instrument in different studies (e.g. [13], [15]). We proposed an augmented social index to that described above, which encapsulates how a social activity index may be measured and used to monitor irregularities from norms or changes in daily life styles. The items monitored included, mobility through pedometers and GPS trackers, frequency and duration of both incoming and outgoing telephone calls and self reported social and described activities from audio diary events. A method was developed to score the persons activity based on the median of each sensors daily accumulated value and using the range of the particular sensor device. To score the daily data, if the sensor reading fell in the normal range a score of 0 was given, if the data fell in the medium range a score of +-1 was given and if the data fell in the high range a score of +-2 was given. The scoring system was developed as deviations from the norm were required and not numeric representations of daily activities. The scoring system is described as a Social Routine Mobility and Activity index and describes frequency of occurrence of described activities on a daily basis. Figure 2 below shows the SRMA of a single individual, which represents an accurate representation of daily social and routine activities.

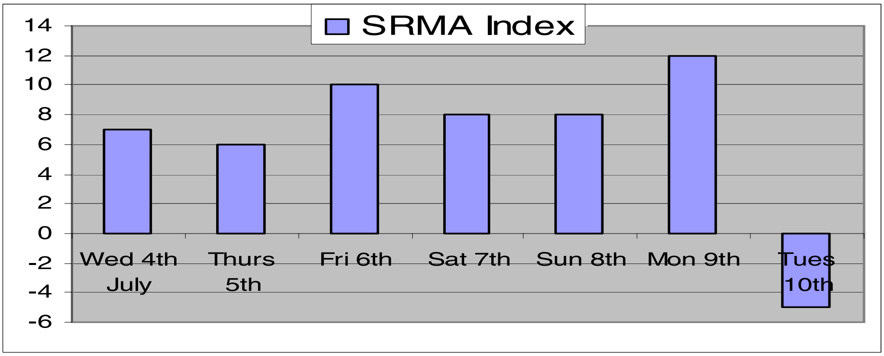

Fig. 2. SRMA data for a single participant (sensors were removed form the home on the morning of Tuesday 10th, so it does not represent a complete day which is visible in the graph)

3 Sleep Versus Sociality Outcomes

Case Study 1: Sleep Quality and Social Routines

Figure 3 shows an example of a "good" and a "bad" night's sleep recorded subjectively by the individual and objectively from the Tactex BEDsensor™ with Table 1 showing numerical values. The actigraphy distinctions are very obvious on good and bad nights' sleep from both the Tactex BEDsensor™ and the actigraph watch data. The individual participant reported anxiety on the night of the 17th (audio diaries), this was due to the fact that they were due to start a new college course the following day. This participant had a restless index (calculated form the Tactex BEDsensor™) of 19% (mean of study 8.51%), which was above normal as traditional actigraphy studies report an average restless index of 5-10% [16].

An interesting observation from this participant was that their sleeping pattern dramatically improved in the second week. The participant started college on the second week, which involved getting up earlier and as a result the participant went to bed earlier but the index of restlessness reduced dramatically in the second week period (Mon, 18th- Thurs, 21st). *Can a conclusion be drawn that regularity of daily routines results in better sleeping patterns?*

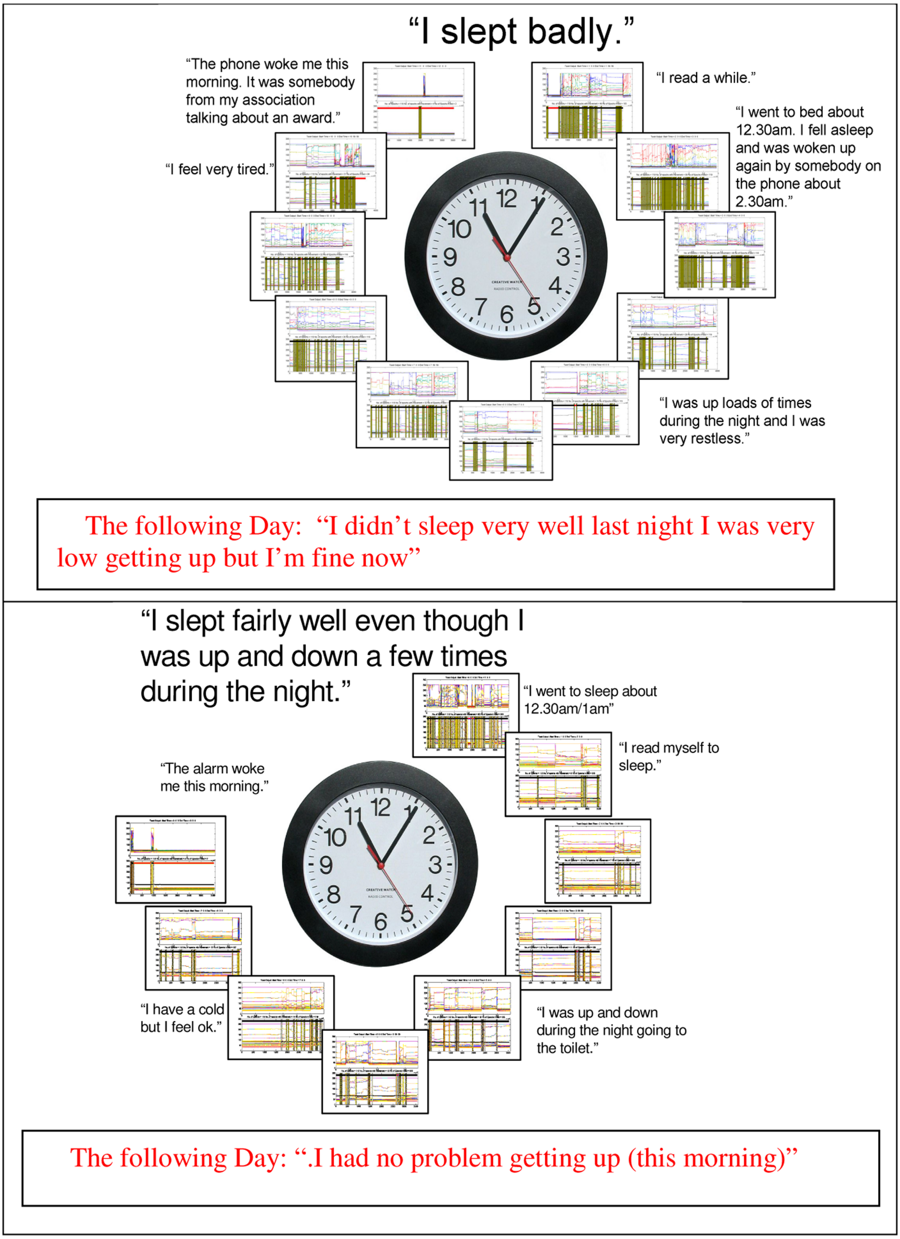

Fig. 3. Graphic representation of a "good" and "bad" night's sleep

Table 1. Objectively recorded statistics for "Bad" and "Good" nights sleep

	"Bad Night" 17th Sunday	**"Good Night" 20th Wednesday**
Time in Bed	10:35:51	7:23:37
No Bed exits	4	2
Length of bed exits	2:48mins	1:30mins
% Restlessness	24.66%	8.75%
Movement Index	26.5%	11.8%
Fragmentation Index	78.7%	41%

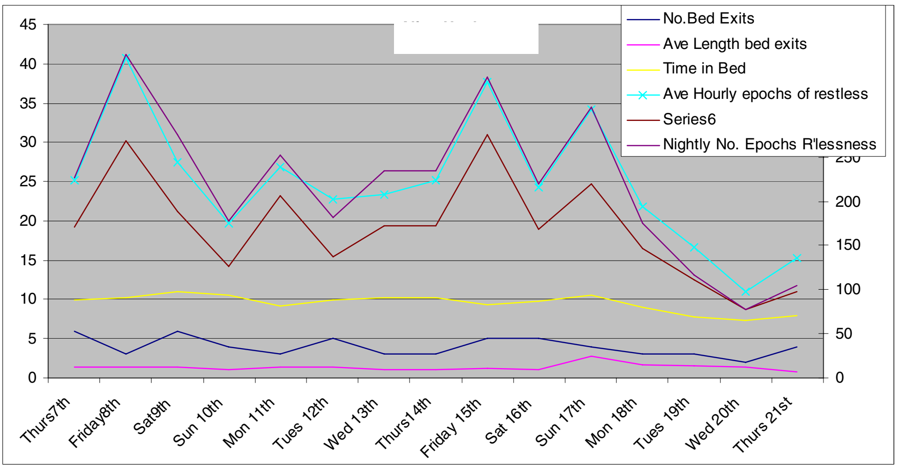

Fig. 4. Sleeping patterns over a two week period

4 Conclusion

This preliminary study examined the daily routines and sleeping patterns of 10 community dwelling older adults over a period of two weeks in a rural village in Ireland. The results are displayed in terms of case studies examining the relationships of subjective and objective data sets and show the routine patterns of both daily and night-time routines. Initial results have shown that cross comparisons between individuals do not work very well due to the variance of individual schedules, but intra-subject variability's and abnormalities can be clearly visible in this method, particularly in sleeping patterns. Strong deviations in daily routines are not distinguishable within this study even when clear disturbed sleeping routines are present thus irregular nights' sleep is very easily monitored as opposed to daily routines. A strong correlation between subjective and objective data is clearly visible when disturbances in sleeping patterns are noticed.

The regularity of sleeping patterns present in this study may be due to the participants' general health as the participants were individuals who are successfully living independently.

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Using Event Calculus for Behaviour Reasoning and Assistance in a Smart Home

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Abstract. Smart Homes (SH) have emerged as a viable solution capable of providing assistive living for the elderly and disabled. Nevertheless, it still remains a challenge to assist the inhabitants of a SH in performing the correct action(s) at the correct time in the correct place. To address this challenge, this paper introduces a novel logic-based approach to cognitive modeling based on a highly developed logical theory of actions - the Event Calculus. Cognitive models go beyond behavioral models in that they govern an inhabitant's behavior by reasoning about its knowledge, actions and events. We present a formal cognitive model for a SH and describe the mechanisms for its use in facilitating assistive living. In addition we present a system architecture and demonstrate the use of the proposed approach through a real world daily activity.

Keywords: Event calculus, cognitive modeling, behavior reasoning, smart homes, assistive living.

1 Introduction

Smart homes have emerged as one of the mainstream approaches to support technology-driven independent living. Extensive research has been undertaken on underpinning technologies such as sensor networks, data communication and fusion, standards, middleware and proof-of-concept prototypes. Whilst significant progress has been made in the aforementioned areas, the challenge still exists of assisting the inhabitant of a SH in performing the correct action(s) at the correct time in the correct place. As such there is an increasing demand for novel approaches and associated methods to enable complex, formal action modeling and reasoning for the provision of Activities of Daily Living (ADL) assistance for ageing people, in particular those suffering from cognitive deficiencies such as Alzheimer's disease [1, 2, 8].

In this paper we propose a novel logical approach for cognitive modeling and event reasoning within the SH. Cognitive models go beyond current implementations of behavioral and reactive models in that they govern what an inhabitant knows, how that knowledge is acquired, and how it can be used to predict consequences and/or infer ensuing actions. The theoretical foundation is the highly developed logical theory of actions, i.e., the Event Calculus (EC) [3]. EC describes complex,

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 81–89, 2008.

dynamically changing worlds in sorted first-order logic incorporating a temporal dimension. With the proposed logical approach, hazard prevention can be mapped to a deductive task such as temporal projection and ADL advising to temporal explanation and/or planning. Within our work we conceive a system architecture to support the implementation of the proposed approach and demonstrate its operations for assisting an inhabitant through the ADL of “making a cup of tea”.

The paper is organised as follows: Section 2 discusses related work. Section 3 introduces cognitive modeling using the EC. Section 4 describes a logical approach to behavior reasoning and assistance. We present an example use scenario in Section 5. We conclude the paper and outline our aspirations for future work in Section 6.

2 Related Work

ADL recognition and assistance in SH have been studied in several strands with the fundamental differences relating to the way the ADL and an inhabitant’s profiles are modelled and represented. One strand is centred on probabilistic methods, which use probability theories such as Markovian model [2] and Bayesian networks [4] for ADL modelling and incorporate the inhabitant’s preferences by tuning the initial values of the parameters of probabilistic models. The major disadvantage with this approach is that the model is static and subjective in probabilistic variable configuration. Another strand of research concentrates on machine learning technologies to identify and extract ADL patterns from observed daily activities, and later use the patterns as predictive models [5, 7]. While this approach increases system adaptation, it suffers from data sparsity and applicability of learning results from one person to another.

Our work belongs to the third strand, i.e., the logical approach that uses logical formalisms for representing ADL models, and deduction or abduction for explanation and predication such as situation theory [6] and lattice theory along with action description logic [8]. Our work is based on the well-developed action theory with the desirable feature of temporal handling that is not possible in other works. The concept of compound actions provides an effective way of incorporating domain heuristics and inhabitant’s profiles, and a flexible way of constructing and reasoning with complex ADLs. Our approach is not dependent on the assumption of inhabitants’ rationality, but based on real world use cases to offer pragmatic and practical solutions in a more intuitive and natural way.

3 Cognitive Modeling

The event calculus is a sorted first-order predicate calculus used for the representation and reasoning of events and their effects [9]. The core components of a logical formalism are ontologies, predicates and axioms. The ontology is used to specify the types of things in a problem domain over which quantification is permitted. The basic ontology of the EC comprises events (or actions), fluents and time points. Events are the fundamental instrument of change. All changes to a world are the result of named events. Any property of a world that can change over time is known as a *fluent*. A *fluent* is a function of the time point. It can take on values ranging from boolean values, i.e. true or false, to any real number or any string literal.

Predicates define relations between entities that specify what happens when, which fluents hold at which times, and describe the initial situation and the effects of events. Table 1 (left column) displays some example predicates together with their explanations. For example, **Initiates**(α, β, τ) specifies the effects of an event, i.e., the fluent β starts to hold after action α at time τ. The EC can handle time-related concepts in these predicates, thus making it particularly suitable for SH where events often happen in relation to time.

Axioms state how and when the truth holds based on causal relations of predicates. Table 1 (right column) gives several examples of axioms. For instance, the first axiom asserts that a fluent f holds at time t if it held at time 0, and has not been terminated between time 0 and time t. Axioms serve as inference rules in reasoning.

Table 1. An overview of the elements of the EC

Some Predicates	**Some Axioms**
Initiates(α, β, τ) - Fluent β starts to hold after action α at time τ	HoldAt(f,t) ⟵ InitiallyP(f) ∧ ¬ Clipped(0,f,t)
Happens(α, τ1, τ2) - Action α starts at time τ1 and ends at time τ2	HoldAt(f,t3) ⟵ Happens(a,t1,t2) ∧ Initiates(a,f,t1) ∧ ¬ Cancelled(a,f,t1,t2) ∧ t2<t3 ∧ ¬ Clipped(t1,f,t3)
HoldAt(β, τ) - Fluent β holds at time τ	¬ HoldAt(f,t) ⟵ InitiallyN(f) ∧ ¬ Declipped(0,f,t)

3.1 Smart Home Formalisation

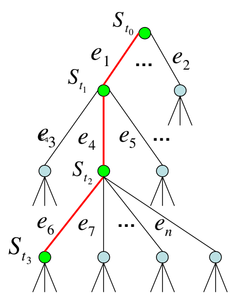

Fig. 1. The Situation Tree

At any specific time point *t*, a SH can be conceptually viewed as a "snapshot" of states, often referred to as a situation S_t. The events, effect axioms and state constraints we have described so far, which can result in many situations, can therefore be thought of as a situation tree as shown in Fig. 1, where e and s refer to an event and a situation respectively.. For example, given a fluent at_location(*location*), an action goto(*location*), an effect formulae Initiate(goto(*location*), at_location(*location*), t) and the formula Initially(at_location(lounge)), we can infer that the inhabitant is in the kitchen at time t_1 following the Happen(goto(kichen), t_0, t_1). The nodes of the tree represent situations or goals, and the links between nodes are events. At the root of the tree is the initial situation S_{t_0}, and each path through the tree represents a possible sequence of events leading to a specific situation (goal).

The cognitive model of a SH, therefore, consists of all events, fluents and the effects of these events that serve as primitive building blocks for situations. They can be formally described in the following:

DomainTheory: A set of declarations specifying all events, fluents and their uniqueness-of-names, state constraints, and effect and causal constraints;

PrimitiveEventEffect: A set of Initiates, Terminates and Releases formulae describing the effects of all primitive events.

3.2 Compound Actions

Many events in SH have causal relations and often happen in a pattern. Inhabitants of the SH are also known to exhibit habits or routine behaviours. In order to model, express and reason about complex actions such as "**If** action α is successful **then** take action β **else** take action δ", "**While** there is a fire alarm **do** run outside and call fire engines**"**, we introduce the concept of compound actions to denote actions that are composed of other actions. To facilitate the construction of compound actions, some additional extra-logical symbols, such as **||, ;, ?, while, if,** etc. which act as abbreviations of control structures for logical expressions have been developed (refer to Table 2 for their definition and semantics). Given that time points are represented by real numbers and arithmetic comparison operators are applicable, compound actions are actually a combination of sequential and/or parallel declarations of primitive actions and compound actions within a time line in terms of these extra-logical symbols.

The occurrences and effects of compound actions can be formalised in the same way as with primitive actions. Therefore, the **DomainTheory** of the cognitive model will contain all compound actions and a set of Initiates, Terminates and Releases formulae describing the effects of all compound events, i.e., **CompoundActionEventEffect.** For convenience we usually denote a top-level compound action as a procedure. During execution, a procedure expands into genuine formulae of the EC that can be reifies, instantiated and reasoned over.

Table 2. Extra-logical control structures

Sequence α;β - do action α, followed by action β.
Nondeterministic choice of actions α | β - do action α, or action β.
Concurrency α || β - actions α and β occur concurrently.
Iteration while *p* do α end - do α while *p* is true.
Conditionals if *p* then α else β - do α if *p* is true, otherwise do β.

3.3 Situation Sensing and Modelling

Events in a SH are dynamic and unpredictable. To accommodate this and provide timely response, an assistive living system needs to perform time-critical assessment of the environment in order to capture the up-to-date status of a situation. Through the use of EC we model the sensing of an environment as a knowledge-production action which does not have any effect on the SH, however, produces the desired effect of changing the knowledge base of the SH's assistive system. We introduce a generic epistemic fluent *Knows* to represent acquired knowledge [10]. The Know fluent specifies the state of an assistive system's knowledge and has exactly the same status as other fluents. The formula HoldAt(Know(ϕ), τ) represents that the assistive system has the knowledge expressed in formula ϕ. Using this epistemic fluent, we can formalize the knowledge producing effects of any actions just like formalizing any other fluents. For example, the effect formula **Initiate**(lookAt(ovenTimer), Know(timeForCooking), *t*) represents that the cooking time in the oven can be acquired by a knowledge producing action "looking at the oven timer".

4 The Logical Approach to Behaviour Modelling and Reasoning

Fig. 2 shows a conceptual system architecture for the proposed approach of behaviour modelling and reasoning. Central to the architecture is the Reasoning Engine, which provides the inference capabilities for manipulating the logical formulae describing events and their effects in a SH. The engine uses recognised observed events as inputs, and infers event consequences or ensuing actions against its *a priori* knowledge. In addition it provides instructions to assistive services to take concrete assistive actions. The *a priori* knowledge is provided through the Inhabitant Profile, the Domain Theory and the Event and Pattern Repository components. The Event and Pattern Repository component contains event and pattern (compound actions) formulae defining the preconditions and effects of events and compound actions. The Domain Theory consists of all events and fluents that are identified as essential and necessary for the description of a SH. It will also define state constraints, effect constraints and causal constraints, which express logical relationships that have to hold between fluents at all times. The Inhabitant Profile component contains details of the inhabitant's profile and habits in addition to their daily life preferences. These can be formalized using the EC formalism and incorporated into the Domain Theory and Pattern Repository components. Domain experts, formal and informal carers and the inhabitant will collaborate to capture and model various types of domain knowledge and encode them into EC formulae into the aforementioned components for reasoning.

The Event Recognition component analyses collected sensor data from various sensors, it recognise the occurrence of events, and passes on the observed events to the reasoning engine for inference. The event recognition algorithm for each individual device should be different dependent on their nature and configuration, which we shall not discuss here in detail. The recognised events will be modelled as a narrative of Happen(anObseredEvent, t_i, t_{i+1}) formula and used as an input for the reasoning tasks, i.e., consequence prediction and/or action advising.

The Behaviour Learning component will use machine learning algorithms against observed occurrences of events to derive ADL patterns from daily observations and populate the pattern repositories automatically through dynamic learning capabilities. This enables assistive systems to capture dynamic and unexpected events and further adapt to their occurrence by using previously observed patterns. The Assistive Services and Actuators component is responsible for the provision of assistance to the inhabitant within the SH. Examples of assistance provision may be audio or video reminding messages, emergency calls being placed to carers or direct activation of actuators for control of the SH environment.

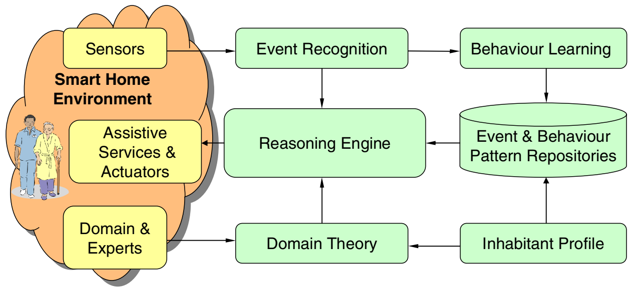

Fig. 2. The proposed system architecture

To reason and advise an inhabitant's ensuing actions, the assistive system works as follows: suppose the system derives an inhabitant's desired goal based on its profile and basic knowledge in relation to ADLs, which is represented as a situation Γ in the form of the HoldAt formulae. Using resolution against formulae in **CompoundActionEventEffect**, the system reasoner system will identify all high-level procedures *ps* that will achieve Γ. The reasoner then decomposes *ps* using resolution against formulae in **PrimitiveEventEffect**. This decomposition may yield any combination of the following:

• Executable primitive actions – which will be compared with observed actions to decide if the next action in the procedure should be recommended. If an observed action appears in multiple procedures, traditional breadth-first and depth-first search algorithms will be applied to decide which procedure the inhabitant will follow.

• Sub compound actions – which will be decomposed further.

• Conditions – which will be tested to determine the truth or false of the condition. If a condition is not met, the system will regard the condition as a goal and seek a sequence of actions to make it true. This process should be exactly the same as we have previously discussed.

The compelling features of the system are as follows: Firstly, as compound actions are built using heuristics and inhabitant's profiles, they reduce the search space of potential event paths to a limited set of paths that are most plausible, thus making the solution more pragmatic and scalable. Secondly, by recursive decomposition an assistive system can decide the next action when the first compound action consisting of observed actions is identified without the need to know in detail the following actions. This subsequently enables advising of ensuing actions in progression order. Thirdly, through rich logical structures an assistive system can specify and further infer complex event patterns such as nondeterministic or concurrent events. It is important to give ADL advice in such situations because the behaviors of an inhabitant with cognitive deficiency are usually inconsistent and nondeterministic.

5 Case Study – Drink Preparation

We shall use the activity of preparing a cup of tea as an example to show how the proposed approach works. The following describes the cognitive model and reasoning processes. (Due to limited space, we do not include all formulae.)

a. Primitive actions: takeTo(*thing*, *location*) - to take *thing* to *location*, add(*thing*, *container*) - to add *thing* into *container*, remove(*thing*, *container*) - to remove *thing* from *container*, boilWater - to boil water, stirAround - to stir, turnOn(*y*) and turnoff(*y*) - to turned on and off device y.

b. Fluents, i.e. state variables: at_pos(*thing*, *location*) - the *thing* is at *location*, inside(*thing*, *container*) - the *thing* is inside the *container*, available(*thing*) - the *thing* is available for use and on(*y*) - the *y* is on.

c. Effect formulae (some examples)

Initiates(boilWater, available(boiledWater), *t*) ← HoldAt(inside(cold water, kettle), *t*)

Initiates(add(teabag, mug), inside(teabag, mug), *t*) ← HoldAt(at_pos(teabag, kitchen table), *t*) ∧ HoldAt(at_pos(mug, kitchen table), *t*)

Initiates(add(boiledWater, mug), inside(boiledWater, mug), *t*) ← HoldAt(inside(teabag, mug), *t*) ∧ HoldAt(available(waterBoiled), *t*) ……

d. Heuristics and inhabitant profile

Suppose that an inhabitant has the habit of adding sugar to tea and of having tea around 10:30am and 4:30pm respectively, and normally spends half a hour to make a cup of tea. Using this heuristic and the background knowledge about making a cup of tea, we can define a compound action makeACupOfTea as a narrative of actions – see e, and represent other ADL profile either as states HoldAt(available(teaReady), 10:30am) and HoldAt(available(teaReady), 4:30pm) or as compound action Happen(makeACupOfTea, 10am, 10:30am) and Happen(makeACupOfTea, 4pm, 4:30pm).

e. Compound action and its effect

Proc. makingACupOfTea {Happen(takeTo(kettle, basin), t_0) ; … ; Happen(add(cold water, kettle), t_2, t_3) ; … ; (Happen(boilWater, t_5, t_6)) || (Happen(takeTo(mug, kitchen table), t_5) ; ... ; Happen(takeTo(sugar, kitchen table), t_{53})) ; waterBoiled ?

Happen(add(teabag, mug), t_7) ; (Happen(add(boiledWater, mug), t_8) ; … ; Happen(add(milk, mug), t_{10})) ; Happen(stirAround, t_{11}, t_{12}) ; …)

Here $t_0 < t_1 < \ldots < t_{53} < t_6$, and $t_7 < t_8 < \ldots < t_{13} < t_{14}$.

The effect formula of the compound action is Initiates(makingACupOfTea, available(teaReady), t_{14}).

f. Initial situation

InitiallyP(at_pos(inhabitant, kitchen)), InitiallyP(at_pos(inhabitant, basin)), InitiallyP(at_pos(milk, fridge)), InitiallyP(at_pos(sugar, cupboard)), and more …..

g. Assistance provisioning

The above cognitive formulae can be mapped into individual components of the architecture. As the assistive system has the makeACupOfTea compound action and knows two desired goals HoldAt(available(teaReady), 10:30am) and HoldAt(available(teaReady), 4:30pm), it can then infer that two compound actions, i.e., Happen(makeACupOfTea, 10am, 10:30am) and Happen(makeACupOfTea, 4pm, 4:30pm), should take place at the specified time points in terms of the effect axioms and the 30 minute requirements from the inhabitant's profile. In this case, if the assistive system does not detect expected actions at the corresponding time, for example, the takeTo(kettle, basin) action around 10am and 4pm, then it can activate reminding services to remind the inhabitant of the activity. Similar assistance can be provided during the process of making a cup of tea if the expected action in the compound action is not recognized in a considerable time. For example, if boiled water is ready for quite long time and the add(boiledWater, mug) action is not observed, then a reminder can be issued.

6 Conclusions

This paper has proposed an EC-based logical approach for behaviour reasoning leading to behaviour assistance within a SH. The concepts of a compound action and its hierarchical construction mechanism enable assistive systems to incorporate ADL heuristics and inhabitant profiles and hence achieve a degree of personalised assistance. The approach avoids the assumptions of inhabitant's rationality and the time-consuming planning processes of traditional approaches. Therefore the proposed solution can be considered to be more pragmatic and with greater potential for wide application. We have developed a conceptual system architecture and demonstrated its use through the scenario of "making a cup of tea". There are many topics which we have not touched upon such as automatic construction of compound actions through learning, inhabitant behavior control, full experimenting and evaluation of the approach. This is considered work for the future.

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Video Monitoring of Vulnerable People in Home Environment

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Abstract. This paper presents a Video Monitoring System, which aims to achieve behavior analysis of elderly people. Real-time tracking and posture discrimination enable to detect emergency situation (by trigging an alarm in case of fall detection for example) and to analyze long term activity which enforces medical follow-up. These are key-issues to improve healthcare quality for rural population. Monitoring human activity in a home environment is a challenging task in computer vision. A multi-camera system is proposed to address the complexity of home environment. Person silhouette is extracted thanks to a robust background/foreground segmentation process. A multi-view particle filter is built to track the silhouette in the scene and discriminate the person posture. This posture is used to interpret basic activities and detect falls. A finer gesture reconstruction is finally exposed which will offer a more accurate activity determination and gait analysis for future system.

Keywords: computer vision, camera network, tracking, posture discrimination, fall detection, long-term behavior analysis.

1 Introduction

Rural exodus is a well-known process in western countries that implies a population concentration in cities generating a degradation of the quality of life (pollution, transport and service congestion, living conditions, poor social life). Maintaining people and attracting new ones in rural areas is a challenge for our society. Global aging of this population must be taken into account in this context and especially about health issue. Two specific problems may be highlighted:

- The medical follow-up is a very critical issue for rural population due to the lack of local care providers or to constraints to access medical centre.
- Enabling elderly and disabled people must live as long as possible in their own social environment sometimes in relatively isolated housing. It corresponds to a old people asking and has huge financial benefits.

Nevertheless in this condition, it is essential to adapt home environment to elderly population concerning health security and medical communication. Digital information and communication technologies are answers to these questions. Our reserach explores some opportunities for providing 'healthcare and wellness' services

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and applications that facilitate more cost effective and efficient solutions. The work presented in this paper will be integrated into a global system dedicated to elderly people management. Mixing sensors, communication platform and smart Human Machine Interface, it will improve both the follow-up care for patients by doctors and the communication tools fitting to both medical staff and elderly people.

One of the novelties of this system is the integration of a video monitoring system that increases user safety by detecting critical situations (falls, immobility). It will also allow the continuous measurement of people activity in the aim to detect subtle changes in their behavior.

The next section gives an overview of the monitoring system capabilities. The third and fourth ones detail the technical content of the presented system. Some experimental results are shown in section 5. As the developed system is continuously improved, the last section describes current and future works that will add new capabilities.

2 Overview of the Video Monitoring System

This system has lot of common objectives with the video analysis of the CareMedia Project [10]. But, our system is restricted to the observation of the patients' room. The number of camera is depending on the complexity of area to monitor but 3 cameras are enough for a large room. The redundancy brought by multi-cameras enables to infer 3D information. This multi-view approach is more robust and gives more consistent information than monocular vision. The functions targeted by this system are listed below:

- **Presence detection and localization:** The system is able to detect and track the patient in its room in real time. The exploitation of a 3D model of the room (bed, armchairs, chairs, TV, table, doors…) is exploited to accurately localize the patient in the room. Patient identification is required to match the right information to the patient. Face recognition on-the-fly is not efficient enough to ensure a robust identification. RFID technology will be integrated to get this information.
- **Falls detection:** The patient is tracked in real time and its posture (sitting, standing, lying) is estimated. An alarm is trigged in case of patient laid down on the floor during several seconds or in case of suspect immobility in unusual place.
- **Activity Monitoring:** The patient is tracked all the day in its room. Using localization data, statistics could be done on "time spent in bed", "sitting on armchair" or "standing". An evaluation of the social activity may be inferred from the time spent out of the room or with visitors.

To respect patient privacy, the Video Monitoring does not deliver images out of the room. Images are processed locally and only semantic information is sending to the application server to be stored in a global database containing (home and wearing medical sensors, medical file). An application has in charge the merge of these outputs in order to generate alarms, storing localization data, building long-term statistics. This synthetic description of activities thanks to this real-time analysis enables the storage of very long period.

The real-time process consists in real time silhouette extraction in each image through foreground/background segmentation. A multi-view tracker merges these silhouettes to get a robust 3D position of the person, coherent with previous localization. The 3D parameters estimated by the tracker are used to estimate the person's posture. These steps are described in next sections.

3 Extraction of 2D Silhouette

Background modeling is a crucial step for many vision-based algorithms. To detect objects of interest, each frame is compared with the background model learned from the previous ones to classify the scene into foreground and background. A huge difficulty is that the background is rarely stable, due to light changes, or shadows for example. Real time performance is also a crucial point.

Recently, block-based methods were presented. These approaches have the advantage of being insensitive to local movements and seem more capable of dealing with non-stationary background. Chen and al. [2] proposed a discriminative descriptor called *contrast histogram,* extended from [3], used to describe each block.

In this paper, a fast background modeling method is presented in the aim of dealing with real-time constraint. Inspired by the *contrast histogram* proposal [2], the method schematically injects a block descriptor in a Mixture of Gaussian system.

3.1 Contrast-Color Descriptor

Given an image, after dividing it into 8*8 pixel blocks, we build a descriptor based on gradient. Each block of the current image is separated into four zones, each one itself being subdivided using two criterions, the sign value of gradients and the color channel. We computed positive and negative contrast values between color channels using the below equation:

$$D^{j,k}_{Z^i,+} = \sum_{p \in Z^i} \frac{\{(p^j - p^k_c) > 0\}}{N_{(p^j - p^k_c) > 0}}, (resp. D_- \approx \sum \frac{\{grad(p) < 0\}}{N_-}) \tag{1}$$

where p_c the centre pixel of the current block, p is a pixel of the zone Zi, j and k two color channel, N_+ is the number of positive (resp. N_-, negative) gradients computed in Zi, D an element of the descriptor for the current block.

3.2 Background Models by Contrast Histogram

A mixture of Gaussian, inspired by the works of Stauffer and Grimson[1], is constructed thanks to the contrast-color descriptor for each block of an image. Secondly the Gaussian distributions of the adaptive mixture model are evaluated to determine which are most likely to result from a background process. Each block is then classified, based on the Gaussian distribution, which represents it most truly, is considered part of the background model. Another way of thinking of our approach is as an exchange between the couple, pixels and color descriptor on one hand, and, blocks and contrast histogram on the other hand, in the MoG approach.

3.3 Foreground Extraction Results and Discussion

Figure 1 presents an example of foreground extraction in a pair of camera. The multi-layer model, continuously updated for encoding changes of illumination, makes possible the exploitation of extracted regions on long period. Specific updating procedures are elaborated to manage sudden change of illumination (light switched on/off, variation of sunlight). The multi-view context enables to be robust to artifacts (for instance, the reflectance on the table close to the window on the right image). The coherent regions with respect to the 2 images are highlighted with the green rectangle.

Fig. 1. Example of foreground extraction (red pixels)

4 Multi-camera Tracking and Posture Estimation

In this section, we present a 3D model-based human tracking method. Inspired by Osawa et al. [4], the model parameters are estimated over time by a particle filter. Thanks to the 3D model obtained, we interpret human action in a home environment. Nowadays, we concentrate our interest about simple attitudes or movements such as standing, sitting, lying down and falling down.

4.1 Tracking Algorithm

We use a very simple geometric model that tracks human body as a planar rectangle oriented in space (fig. 2.). We represent it by a 5D vector (x, y, α, w, h) where the couple (x, y) represents the 3D position on the ground, α lay out for the orientation angle of the model in relation to a world reference, and w and h indicate the height and width of the rectangle. Although this simple model does not perfectly fit a human silhouette, it strengthens the robustness of the tracking system, it is fast to compute and it gives good results. Particle filter is a sophisticated Monte-Carlo sequential estimation technique to approximate a probability density function (PDF) of a target object state by a set of random samples with associated weights $S_t = \left\{(s_t^i, \pi_t^i) \middle| (i = 1...N)\right\}$ (see [5] for details). In our 3D tracking algorithm, particles are recursively sampled in the 5D state space (x, y, α, w, h) to represent the posterior PDF, given all observations of the target, in a Sequential Importance Re-sampling (SIR) scheme. The systematic re-sampling stage avoids the problem of particles degeneracy. Because no assumption on the person movement can be made, we use a 0-order dynamical model with Gaussian noise in the prediction step. The measurement step involves the computation of particle weights, defined by:

$$\pi = \prod_{n=1}^{N} \frac{proj_n(R) \bigcap B_n}{proj_n(R) \bigcup B_n} \tag{2}$$

where N is the number of camera views, *proj(R)* is the projection of the human model in the view n, and B_n the silhouette extracted by background modeling.

The sample weights relate how the 3D human model projections fit the detected silhouette in all camera views.

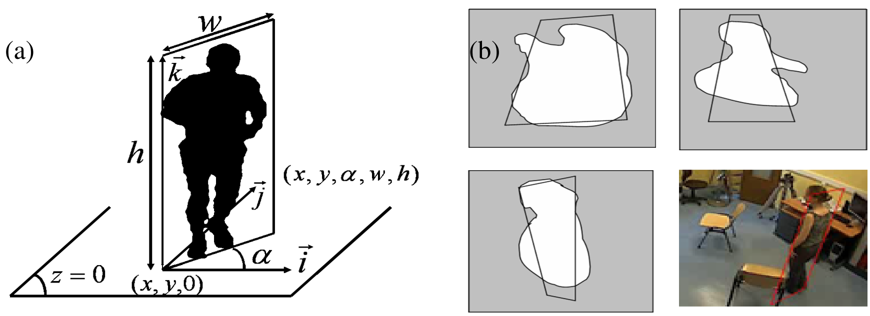

Fig. 2. (a) Human geometric model. (b) Multi-view weights combination

4.2 Posture Discrimination

Our objective is to understand human action in a home environment. We choose to focus on basic actions recognition as standing, sitting, lying down. We define simple rules from the geometric model of a silhouette to solve this problem. These rules, based on the ratio w/h of the 3D rectangle, give us promising results. In the hope to better discriminate simple human actions and works more complex ones, the next step appears to be the integration of 3D model of the scene. We also explore a different approach that try to fit a more complex human model to the silhouette extract in the first steps (see section 6). The knowledge of the posture combined with the elapsed time make possible the detection of critical situations. The most obvious is the fall of the person on the ground which must be detected. More complex situations can be tackled as suspect immobility; the description rules must be adapted to each person with respect to its profile. In case of ambiguous situation, alert could be confirmed or infirmed by the person using acknowledgement procedure through adapted interface.

5 Experimental Results

The Video Monitoring System is intensively tested in laboratory and will be integrated into an elderly residence. Figure 3 presents examples of posture estimation. Very robust results are obtained on real sequences thanks to the quality of foreground extraction and temporal coherence on shape evolution given by the 3D tracker. A posteriori temporal filtering smoothes posture estimation. In home environment, people are often partially viewed; the chosen multi-view approach makes the tracker robust to these occlusions (see Figure 3). Moreover, we plan to integrate a scene model through an occupancy map, updated with object displacements (ex. chairs).

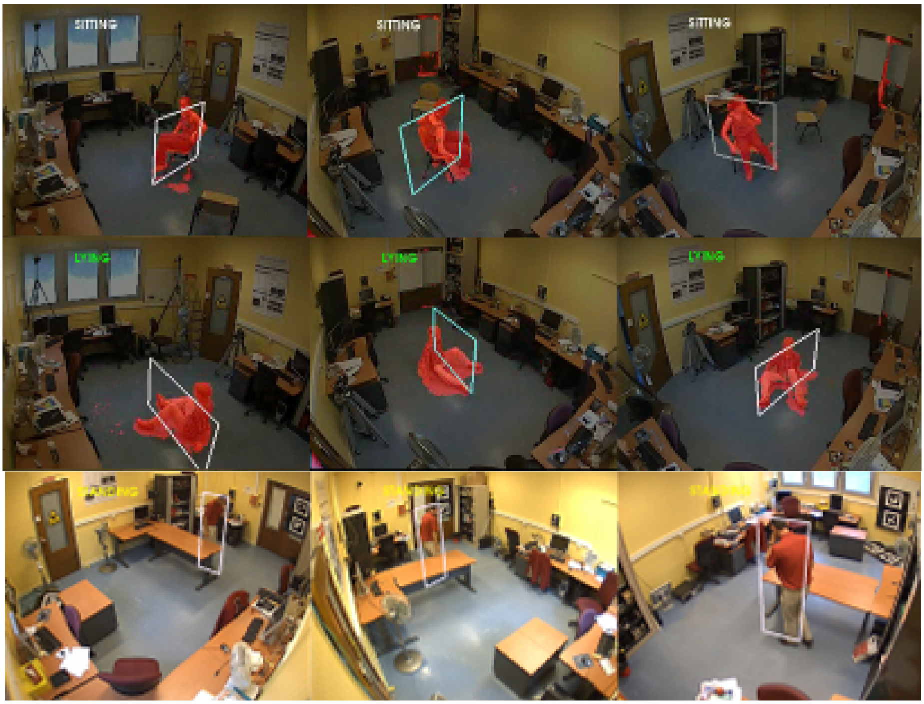

Fig. 3. Posture discrimination (sitting, lying and standing) on sequence samples in presence of occlusions (last line)

6 Perspective Works

The system has to run day and night. In order to avoid the use of expensive night vision cameras, we are integrating a volumetric motion detection to switch on automatically a progressive light in case of night wake-up. This system makes the video system efficient and is also useful for the user. More generally, our objective is to combine Video Monitoring outputs with other sensors. It concerns environment sensors/actuators but also medical information from wearing sensors or recurrent analysis. The redundancy of information sources would increase robustness of estimations and would enable to broad the range of pathologies detected with this system. For instance, little variations of biological parameters (blood pressure, temperature, heart rate) might be highlighted by the detection of unusual activity. The correlation of these independent sources may be useful for cross medical diagnosis.

The current system is able to track the patient in his room and estimate his global posture (sitting, lying, and standing). Our objective is to introduce more accurate information on localization and behavior of the patient. First, strategic places will be defined in the room as bed, armchair, chairs and doors. This information will give a more precise description of real actions of the person during its everyday life. Second, the analysis of human activity would be more selective using exact motion of the persons. We propose in [9] a method to extract human gesture for our multi-view system, which solve lot of visual ambiguities. The objective is to estimate in real time the body internal angles. The 3D visual hull of the person is built from the different images and is composed of elementary cubic elements (voxels). This 3D shape is encoded using a descriptor which divides space into sectors (see Fig. 4).

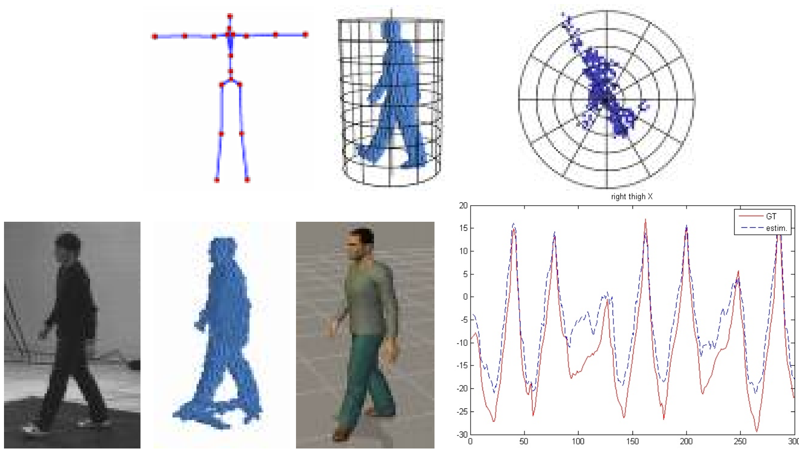

Fig. 4. Body model (up-left) -3D descriptor: side (up-center) and top view (up - right) - Image/3D silhouette/Posture (bottom left) – Estimated angle (blue curve) and ground truth (red curve) for the thigh on a walking sequence (bottom right)

For each posture, the description vector represents the rate of voxels occupancy in each sector. A database containing several examples of posture and 3D visual hull is used to train a SVM algorithm to map internal angles to descriptor content. This process gives internal angle measurement in real time. The targeted accuracy is dew degrees on each angle (see Fig.4). The posture estimation will be integrated in the global activity recognition process. Our goal is also to exploit this measure to achieve gait and gesture analysis in order to detect health degradations from functional abilities changes.

The Video Monitoring System is going to be integrated in an elderly residence for intensive testing in real conditions of use. Nevertheless, a more global context of housing is targeted to maintain people in their own home. The first prototype will manage an individual room. The experience acquired will be used to develop systems able to manage complex home with several rooms, taking into account specific activity in kitchen, or bathroom. Extending this monitoring out of the private area rises lot of problems both legacy (privacy) and technical (tracking several people in a complex camera network is still a scientific challenging task) as shown in [10].

7 Conclusion

This paper has presented a Video Monitoring System which aims to perform behavior analysis of elderly people. The tracking and posture discrimination enable both the detection of falls (to trig an alarm) and the elaboration of long term activity synthesis through real time processing. Future works will enrich the activity analysis and very fine gesture analysis will also be presented. This tool is useful for the whole elderly population and more particularly for rural persons, which are far of care facilities and often lonely in their house. This automatic service is connected to the care providers for emergency case of course but also to reinforce prevention by the detection of symptoms at a very early stage of diseases. Indeed, this system optimizes the medical follow-up, which is a very critical issue for rural population due to several factors (lack of care providers, access to medical center).

Acknowledgements

This work is a part of the ITEA-Nuadu project (www.nuadu.org) and is funded by the General Directorate of the French Ministry of Economy, Industry and Employment.

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An Efficient Method for Activity Recognition of the Elderly Using Tilt Signals of Tri-axial Acceleration Sensor

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Abstract. We propose an activity recognition system for the elderly using a wearable sensor module embedding a tri-axial accelerometer, considering maximization of battery life. The sensor module embedding both a tri-axial acceleration sensor and an RF transmission module is worn at the right side of one's waistband. It connects and transfers sensing data to subject's PDA phone. Then, an algorithm on the PDA phone accumulates the data and classifies them as an activity. We utilize 3 tilts in addition to 3 acceleration values, compared to previous works. However, we reduce the sampling rate of the sensing data for saving battery life. As an activity classifier, the SVM (Support Vector Machine) algorithm is used, and we have achieved 96% of accuracy in detecting an activity out of 9. It shows the proposed method can save the battery life without losing the recognition accuracy compared to related works.

Keywords: Activity Recognition, Saving Battery Life, Tilt Signal, Tri-axial Acceleration Sensor.

1 Introduction

Falling down is dangerous especially to the elderly since it causes an irreversible situation such as serious aftereffect or even death. Therefore, many researchers [1, 2, 3] have tried to automatically recognize such critical situation as well as general activities of daily living using tri-axial accelerometer. Most of them have focused on how effective their proposed ideas are. It means they have worked on improving the accuracy of how well their approaches classify sensing data, without caring about addition issues such as narrow wireless coverage and battery shortage problem. To be more practical, the methods proposed by previous researchers need to be advanced, because the battery shortage problem, for example, should be considered in step of modeling the algorithms.

Actually, Nyan[1] and Tong[2] had focused only on developing good quality of methods for activity classification. And they used 350(2660 for long term activities) samples and 512 samples per second respectively in order to recognize real-time activity. However, considering the limited battery on the sensor, such frequent sampling

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may cause the enormous loss of battery while transferring sensing data to a processing module (PDA in our case) even though their works performed well. Therefore, in this paper, we propose an activity detecting method using 3 tilts and 3 acceleration values, saving the battery life by reducing the sampling.

2 Method

Figure 1 depicts the proposed system in this paper. The system consists of a sensor module worn at subject's waist, cellular phone with GPS belonging to the subject, and a management server connected to the cellular phone with data communication method.

The scenario is like this. The sensor gathers 3 acceleration values and derives 3 additional tilt values, and transfers them to the dedicated cellular phone periodically. Then, activity recognition software on the phone receives and classifies them to an activity. In case of emergency, such as falling down, the phone sends the situation with GPS information to the management system. The management system, then, warns family, caregiver, or hospital about the situation.

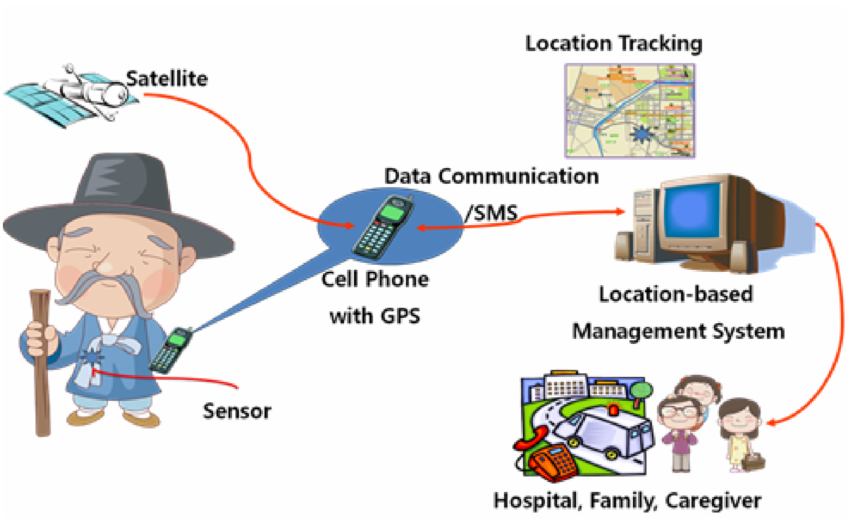

Fig. 1. System Architecture for the Activity Detection System

2.1 Materials

The activity classification system proposed here consists of three parts, which are a sensor module containing tri-axial accelerometer, a PDA phone with a Zigbee dongle, and a management server logging results and dealing with the emergency situation. The sensor module sends tilt data as well as acceleration data for the three axes each. The tilt and acceleration values used here are derived from the raw acceleration values using the Low/High-pass filtering method which are widely used in Signal Processing. We utilize an MMA7260Q chip as tri-axial accelerometer and a PDA phone which contains WinCE as operating system. We choose programmable PDA phone based on WinCE, because built-in cellular phones, in general, do not allow user-created software to be newly installed.

In figure 2, the (a) and (b) are the PDA phone and the sensor module. The PDA contains activity recognition software. The (c) shows a subject wearing a sensor on her waist.

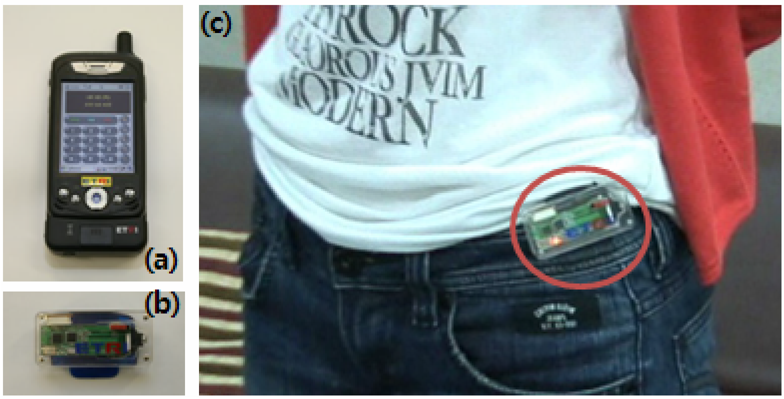

Fig. 2. Experimental Setup: (a) a PDA Phone with a Zigbee dongle attached at the bottom (b) a sensor within a transparent case with a clip to buckle on one's belt. (c) A subject wearing the sensor module.

2.2 Sampling Sensor Data

The acceleration data is delivered at most 14 times per second, 6 features per each (3 accelerations and 3 tilts for three axes). Compared to Nyan[1] and Tong[2], it's quite small amount of samples since they used 350(2660 for long term activities) samples and 512 samples per second respectively. This reduction of sampling rate saves the RF transmission overhead outstandingly with no doubt. However, it may cause inaccurate classification of subject's activity. Therefore, we add tilt data for three axes respectively hoping that the addition compromises the loss. Deriving the tilt values through the Low/High-pass filtering has done at the microcontroller in the sensing module. So, the sensor module can saves the battery by reducing the sampling frequency from hundreds to tens.

2.3 Classification of Activities for the Elderly

We applied SVM (Support Vector Machine) algorithm [4], one of the most widely used machine learning algorithm. As an input vector, 14 samples including 6 values each (3 acceleration and 3 tilt values) per second are used.

In order to classify activities more accurately, we uses previous 14 samples in addition to current 14 samples. Therefore, 28 samples are used as an input vector. However, instead of increasing sampling frequencies per second from the sensor, we simply reuse the previous samples stored in memory. It means an activity is decided based on two seconds samples. Usually, an activity would be done in around one second. However, considering elderly people, they need more time in doing an action.

2.4 Activity Labeler

We have built an activity logging/labeling tool which is able to record both the subject's movement into a video clip and the sensor data simultaneously, so as to make it possible to label the subject's activities afterward. On-the-fly labeling of user's activity is not quite effective since it is almost impossible to pick the exact moment out on the fly especially in milliseconds while subject is acting. The screenshot of the logging/labeling toolkit looks like Figure 3.

On labeling an activity, it is bounded in a time slot. A time slot is 1/14 second. Since the sampling is done every 1/14 second, every activity would be a set of time slots. For example, if an activity, falling down, starts at 10 and 3/14 seconds, and ends 11 and 5/14 seconds, it is done during 16 time slot, that is, 16/14 seconds.

Fig. 3. Activity Labeler with Video Recording

3 Experiments

We detected 9 different activities including the falling down, which are Sit-to-stand, Stand-to-sit, Lying, Lying-to-stand, Stand-to-lying, Walking, Running, sitting, and Falling down. The falling down is again divided into 4 categories such as left, right, backward, and forward fall.

The experiments were performed on 5 male and 2 female subjects (age ranged between 28 and 72, height between 157cm and 181cm, weight between 47kg and 71kg). We recorded their simulated plays as a video as well as the sensing signal from the tri-axial accelerometer simultaneously in order to obtain training and test data sets described earlier. The total number of the samples we used in the experiments is 5773 including 274 cases of falling down. The case in the experiments means the time slot rather than an activity.

Figure 4 shows the number of cases for each activity.

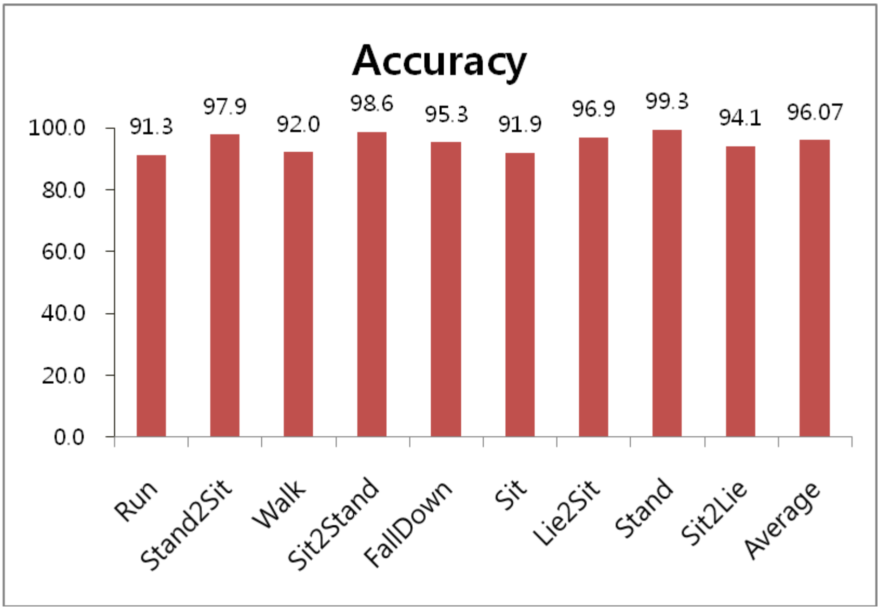

Fig. 4. The number of cases for each activity: # of cases; 538(Run), 1332(Stand to Sit), 591(Walk), 1383(Sit to Stand), 274(Fall down), 571(Sit), 192(Lie to Sit), 604(Stand), 288(Sit to Lie), 5773(Total cases)

4 Result and Conclusion

Table 1 shows the result of the experiment of inferring activities using the SVM algorithm for 9 activities. In spite of reducing the number of sample, we can get similar classification accuracy compared to the related works [1, 2].

Each row in the table shows the frequencies of labeled activities. For example, in 5th row, the 274 cases of falling down are assigned to each category from Run to Stand-to-lie by the proposed method. The frequencies of all columns in the row

Table 1. Confusion Matrix of Activities

Activities	Run	St2Sit	Walk	Sti2St	Fall	Sit	Lie2Sit	Stand	Sit2 Lie	Error
Run	491	30	1	3	4	8	0	0	1	47
St2Sit	2	1304	0	1	0	25	0	0	0	28
Walk	0	1	544	16	2	10	8	0	10	47
Sit2St	1	1	8	1364	0	5	2	2	0	19
Fall	5	0	2	2	261	2	0	1	1	13
Sit	3	30	1	6	0	525	6	0	0	46
Lie2Sit	0	0	4	0	0	1	186	0	1	6
Stand	0	0	0	1	0	0	0	600	3	4
Sit2Lie	0	0	10	0	0	0	0	7	271	17

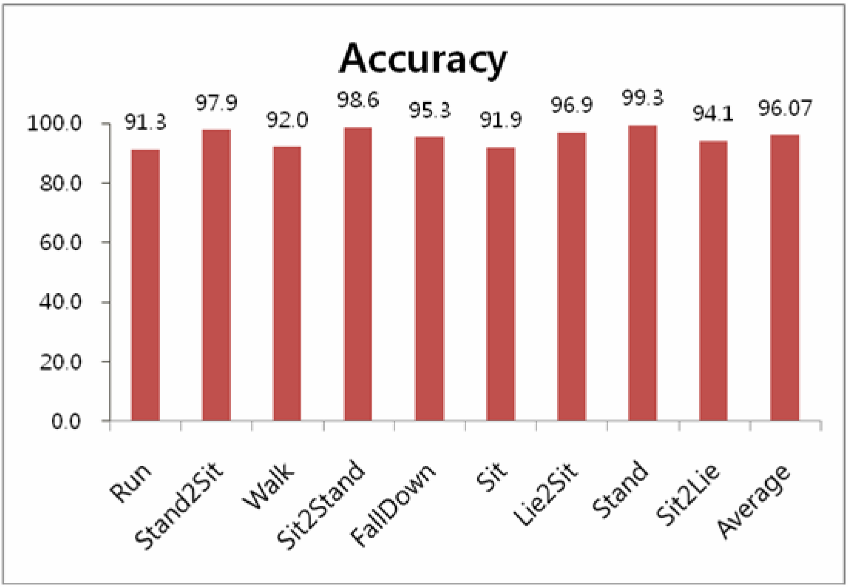

Fig. 5. Accuracy Graph

except ‘E’ column mean false-negative cases. In the case of falling down, we have got 95.3% of accuracy.

Consequently, we have proved that we can save the battery life while maintaining the recognition accuracy compared to the previous works [1, 2].

Acknowledgments. This work was supported by the IT R&D program of MKE/IITA[2006-S-007-02, Ubiquitous Health Monitoring Module and System Development].

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A User Interface Level Context Model for Ambient Assisted Living

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Abstract. Within Ambient Assisted Living (AAL) context awareness is an important feature of intelligent user assisting services. In this domain different requirements regarding context modeling can be identified that are not in the focus of current context models. One important aspect is the support of an end user interface for describing context dependent service behaviour. An inhabitant of a smart home needs to get and give feedback on context in a way that can be understood and handled without context modeling expertise. At the same time such simplified context description must be matched on the technical details of context sensing and context dependent service adaptivity. In this paper we introduce a layered context model for AAL which provides different abstraction levels. Therein we focus on model elements and concepts on the user interface layer.

Keywords: Ambient Assisted Living, Smart Home, Context Modeling, User Interface, Context Adaptive Applications

1 Introduction

The term ‚Ambient Assisted Living' (AAL) is used to describe technologies which help to extend the time where older people can live in their home environment by increasing their autonomy and assisting them in carrying out activities of daily life. This technology is based on the installation of a smart home environment which integrates into the human living space and interacts with the inhabitant. Technologies that are relevant in the application domain AAL come from the research areas 'home automation' and 'ambient intelligence'.

Research within Ambient Intelligence follows the goals of Ubiquitous Computing, which had been stated by Mark Weiser [1]. The computer should become invisible for the user. Instead the user should communicate with an intelligent environment naturally, which supports him in his goals. Natural interaction is achieved by providing interface support for language, movement, gesture and pointing [2]. Context awareness is also important to support natural interaction and to provide proactive services.

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 105–112, 2008.

Based on these key technologies AAL services can be provided which integrate into the human's living space and provide intelligent assistance. Examples for AAL services can be found in [3]. We have developed and tested a number of AAL services in our project 'SmarterWohnen' [4] together with a local housing company in the city of Hattingen, Germany. A number of developed AAL services have been deployed in apartments, which have been equipped with OSGi based sensors and devices. These services are now used by a number of selected tenants. They include water and gas leakage detection, intrusion detection, house automation and health related services like the supervision of vital parameters.

We have implemented a context subsystem as part of the service platform, which we have used in our projects. From our experience the development of context aware services for AAL puts special requirements on context modeling. A consistent modeling approach is needed that supports different aspects of using context: dynamic integration of context sensors into a smart home environment, definition of service specific context models and especially end user interface support for describing context dependent service behaviour. Current context modeling approaches do not fully meet these requirements. The concepts which we introduce in this paper focus on the user interface level and are part of the implemented context subsystem.

The rest of the paper is organized as follows. In the following section we discuss the related work. After that we identify the special requirements on context modeling from the view of AAL. Then we give a short description of our three-level context model which we use for building AAL services. Finally we describe the user interface level of the context model more in detail and its interdependencies with the lower levels and end with a conclusion.

2 State of the Art

According to Dey [5] context is "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves". A context model is a formal description of the relevant aspects of the real world. It is necessary to abstract from the technical details of context sensing and to connect the real world to the technical view of context adaptive applications [6]. There are already a number of approaches for context modeling introduced into the context awareness community. In [7] an overview on actual approaches is given. For example context models based on simple name-value-pairs have been used for annotation of services with context information [8]. XML-based context models have been used for providing context profiles, e.g. the comprehensive structured context profiles (CSCP) [9]. Currently ontology based context models are discussed in the research community, e.g. in [10].

In [11] some requirements for context models in AAL are identified: application adaptivity, resource awareness, mobile services, semantic service discovery, code generation and context-aware user interfaces. Based on these requirements an extensible context ontology is introduced that is focused on four main aspects: user, environment, platform and service. Based on that ontology services can be built that can adapt to changes along these four aspects.

One import aspect in context modeling for AAL is the provision of suitable user interfaces for the communication of context information to and from the elderly inhabitant. In [12] some requirements are identified that are specific from user interface design for AAL services. Especially the acceptance of such user interfaces from elderly people is a key point in AAL. In [13] a solution is proposed by providing a graphical programming language based on event-condition-action rules. Some technical skills are still needed in this approach which cannot always be presumed from elderly people.

3 Requirements

Requirements which have been identified in existing approaches are also valid for context modeling in AAL. In the following we will focus on requirements concerning context modeling on a user interaction level. First we describe a scenario in order to demonstrate these aspects. Then we identify the resulting requirements.

3.1 Scenario

This scenario is about elderly Mr. Bond who is moving into a smart home. The initial set of context aware AAL services is not sufficient for his needs. Therefore he is extending his set of services using an open service marketplace. In order to use the full functionality of his smart services, he is also extending the capability of the context environment by adding new context sensors. Then he is customizing the contextual behavior of the services according to his needs.

The initial set of context adaptive services for Mr. Bond includes a reminder service, which provides reminders depending on time-related context conditions. Mr. Bond adds a daily reminder to take his medicine at 8 pm. He thinks that it would be great if the reminder could be limited to those situations where he actually forgot to take his medicine. Mr. Bond tries to activate the health related context conditions. Since it is not supported by the context environment, the application is advising to add a new context sensor regarding the status of the medicine cabinet.

Mr. Bond thinks that it would be great to extend his set of AAL services with some functionality that could give him more control on the fancy smart devices in his department. He selects a house automation service from the AAL service marketplace and adds it to his application set. He starts to configure the new service. A number of smart devices are listed and also the actions that can be defined on them. Mr. Bond selects the lightings. He wants to have them turned on in the room where he is located, when it is dark and he is not sleeping. Mr. Bond gets informed that this service cannot be provided accurately, since there is no brightness sensor in his context environment. Because of the missing sensor also the functionality of detecting broken lights is not available.

Mr. Bond engages a service provider to extend his context environment with the identified context sensors. After the new context sensors have been integrated in the context environment Mr. Bond starts to reconfigure his services. Mr. Bond is now satisfied with his services and enjoys the electronic assistance of his smart home.

3.2 User Interface Requirements

Based on the scenario the following requirements regarding context modeling on the user interface level can be identified:

- The end user needs to define the context behaviour of his AAL service without high technical skills. The context model on this level has to abstract from the technical details and complexity from context modeling on the sensor and application levels.
- The selection of AAL services and the context dependent provision of their functionalities are limited on capabilities of the context environment. The user needs feedback on which functionalities can be supported and how to gain full support.

Additionally the following requirements can be identified:

- An inhabitant might from a privacy perspective be interested in information about what kind of context information is used by the application in order to provide the desired adaptability.
- In a ubiquitous environment where the behavior of services does not depend on explicit user interaction it is necessary to give feedback on the system's assumptions that lead to desired or possibly undesired actions. The environment has to provide means for the user to control and to make corrections to the assumptions about the relevant context.

Summarized, a user interface context model must provide means to communicate different aspects of context information to the inhabitant in a way that hides from the complexity of context modeling and is easy to understand and handle.

4 AAL Three Layered Context Model

In our approach we have organized the different aspects of context modeling into three layers: infrastructure, service adaption and user interface.

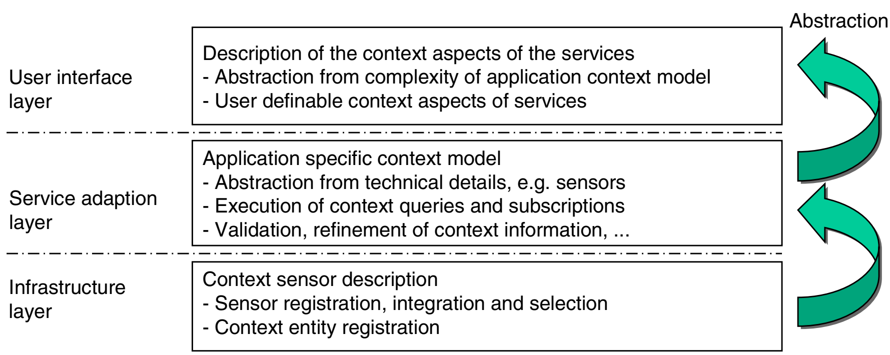

Fig. 1. Three layered context model

Requirements on the three levels differ from each other. Consequently context modeling and the implementation of a context model on the three layers is different. However, the context models on the three layers are not independent from each other. The three layers represent different abstractions from technical description of context to a user oriented representation.

In this paper we focus on the user interface level and its interdependency to the service adaption level. More information on the service adaption and infrastructure layer can be found in [14]. In the following we give a short introduction into the relevant elements of the context meta model on the service adaption layer. Then we describe the context model elements of the user interface layer and show the connections between these two layer specific context meta models.

4.1 Service Adaption Layer

The context model on this layer describes the context aspects that are relevant for the adaptivity of an AAL service. Our context subsystem provides methods that operate on this layer. Most context models identified and evaluated in [7] can be mapped to this layer. The meta model of our approach defines the concepts that are also common in most existing approaches:

- Context Entity: A context entity is named and represents a physical or conceptual object, e.g. person, building, electronic device, etc.
- Context Dimension: A context dimension represents potential common properties of context entities and relations, e.g. time, status, position, etc.
- Context Attribute: A context attribute describes a concrete property of a context entity or context relation by relating it to a context dimension.
- Context Relation: A context entity is related to another context entity by a uni-directional relation. A special relation is the generalization relation between context entities.

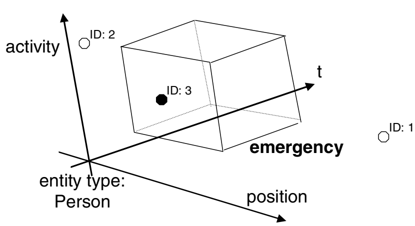

Fig. 2. Named context subspace

All possible states of a concrete context model describe the valid context space. The definition of context subspace is an extension to the basic context meta model. A context subspace is defined by selecting the relevant context entities and relations of the context space and by setting constraints on their context dimensions. These subspaces are then named and represent a corresponding situation.

4.2 User Interface Layer

The context model of the user interface layer abstracts from the complexity of a service specific context model. In our approach we restrict context modeling on this layer to the selection and further refinement of already predefined situation descriptions. Predefined situations are represented by a situation taxonomy. Each element of the taxonomy additionally has a graphical representation and a textual description. At least the leafs of the taxonomy are associated to one named context subspace of the service adaption layer.

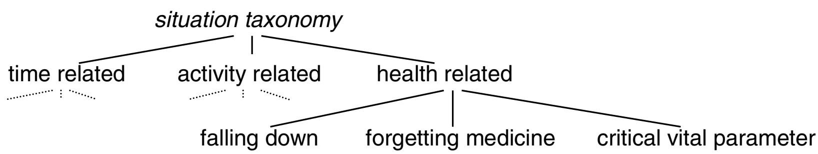

Fig. 3. Example situation taxonomy

The graphical representation is used to give feedback on the system's assumptions regarding the relevant context. It can be shown highlighted in place of a detected situation. The inhabitant can select and deselect it in order to make manual corrections.

An AAL service can have a number of context adaptive functions, e.g. give a reminder on a specific situation. The adaptiveness of the function depends on the capabilities of the context environment, e.g. available context sensors. The inhabitant therefore needs feedback on limitations. In our approach meta information about the AAL service is given, which describe the context adaptive functions including the situations that can be applied on them. Based on this service description and the predefined situation taxonomy the support for these functionalities is identified. For each situation description of the function the service adaption context model is queried regarding the infrastructure support for the associated context subspace. The functional limitations depend on the results of the queries, e.g. limited situation support or even no service provision.

```
<situationTaxonomy>health</situationTaxonomy>
<contextAdaptiveFunctions>
        <function>
                <name>sendReminder</name>
                <forSituations>
                        <situation name=„time related“/>
                        <situation name=„activity related“/>
                        <situation name=„health related“/>
```

Fig. 4. Example service description

User specific definition of the contextual behaviour of an AAL service also relies on the predefined situation taxonomy and the service description. The user selects a function that he wants to configure. In a first step the most general elements of the situation taxonomy that cover the set of situations from the service description are presented to the user. In a second step the user can navigate through the taxonomy of supported situations. While navigating he can then select a situation description which is associated to a context subspace. In a third step the user can further specialize the selected situation description. The specialization process depends on the meta information which is part of the service adaptation layer context model of the associated context subspace. In the following examples we assume a situation definition 'meeting people' which is described by a relation between context entities of the type 'location' and 'person'. The following specialization options are provided:

- Specification of the cardinality: If the context subspace consists of a relation between two or more context entities, then the cardinality at the relation can be specified. A specialization of that situation can be defined by setting the number of entities of the type 'person' within the relation to '>5'.
- Selection of specialized context entity: The user can select a more specialized context entity if it exists to a context entity which is part of the context subspace. An entity type 'neighbor' can be selected as specialization of 'person'.
- Setting constraints on context attributes: Depending on the related context dimension, constraints can be set on the selected attributes of a context entity or relation. The attribute 'age' of the entity type 'person' can be set to '>50'.

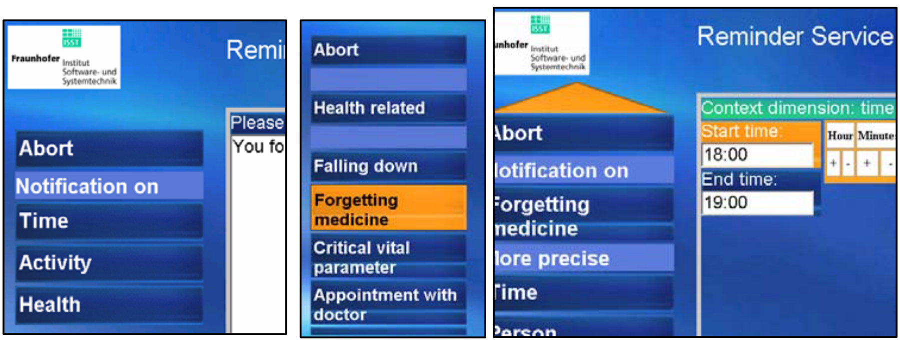

Fig. 5. Interaction: situation taxonomy, navigation, further specialization

The user interface for defining the contextual behaviour depends on the situation taxonomy and the associated context subspace of the service adaption layer. It is part of our context subsystem of the smart home environment.

5 Conclusion and Future Outlook

Context modeling in AAL has to provide a consistent approach that supports different aspects of using context: integration of context sensors, service specific context models and end user support. We have identified requirements towards context modeling from AAL and propose a three layered context model. The user interface layer provides an abstraction that allows the end user to define the contextual aspects of his AAL services. This abstraction does not provide the full expressiveness of the underlying layer, but it allows a guided definition process by selection and further refinement of already predefined situation descriptions. A final evaluation of the usability and the restrictions of this approach will be done in a following step.

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Abstracting Nutritional Information of Food Service Facilities Using the Pervasive Healthy Diet Adviser

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Abstract. It would be surprising to find a news publication in the United States today without a mention of words like obesity, diabetes and diet. This is a reflection of the growing awareness worldwide about the importance of a healthy diet in preventing nutrition related chronic diseases like obesity and cancer. A recent study by the United States Department of Agriculture reports that Americans spend more than half of their food dollars on meals at food service facilities. This means that the nutritional content of the food that these facilities provide is an important determinant of national health. We present PHDA, a diet advising application that leverages the power of preventive medicine and ubiquitous computing to help its users choose a healthy diet. Specifically, we discuss the fidelity of different mobile device based peripheral displays in abstracting nutrient data of the food, served in food chains around the country.

Keywords: Peripheral ambient display, Preventive Medicine, Nutritional Information, primary healthcare, ubiquitous computing.

1 Introduction

Four of the top ten medical causes of death in the US today are chronic diseases with well-established links to diet: coronary heart disease, diabetes, stroke and cancer [1]. With 12% of the population suffering from cardiovascular disease [2] and 7% of the population from diabetes mellitus [3] these statistics are alarming. Obesity, which is a dependent and independent risk factor for these conditions, is also at a record high of 64.5%. [4] This is bad news - especially in the existing scenario with rising healthcare costs (8.1 % of the GDP in 1995 to 16.0 % in 2005) [5] and the steady growth of the elderly population (10 % increase since 1996 in population above 65 years). [6] Chronic diseases are known to present with frequent complications, like retinopathy for type 2 diabetes mellitus, which further strain the healthcare system and deteriorate the quality of lives for the patients.

What lies at the epicenter of the web of causation of these ailments is the most universal of human needs, a healthy diet. This seemingly simple concept is fraught

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 113–122, 2008.

with complexities and controversies. There have been conflicting views about what comprises a healthy diet from the medical and the scientific communities over time. The most important of such views has been a thirty-year-old belief that dietary fat is responsible for chronic disease also known as the lipid hypothesis. [7] This hypothesis which resulted in a lot of focus on the type of fats, saturated vs. unsaturated, has recently received a string of criticism from the scientific community, eloquently termed as the melting of the lipid hypothesis. Another such philosophy, which has received a lot of commercial attention, is the Atkins diet which predominantly focuses on a high protein intake. Carbohydrate recommendations over time have also been confusing in terms of different forms of consumption like complex starches vs. simple sugars. The historical trends in food production and consumption have not been stable over time either. The rise of highly processed foods and refined grains, abundance of cheap calories from carbohydrates and the use of fertilizers and chemicals in agriculture have all added to the conundrum. Thus the question, “what is it about the American diet that is making Americans increasingly obese and unhealthy?” is not an easy one to answer.

A very important force that has modeled the shape of what Americans eat has been the commercialization of food. The food marketing system, including food service and food retailing supplied about $ 1.02 trillion worth of food in 2005 of which $ 496 billion was supplied by food service facilities that serve meals and snacks for on premise or immediate consumption (food away from home). [8] Full service restaurants and fast food restaurants – the two largest segments of the commercial foodservice market account for more than 77 percent of all food-away-from-home-sales. It is thus impossible to try and address the problem of procuring healthy food without factoring this gargantuan nutritional industrial complex in the scenario.

2 Technology for Human Transformation

Researchers and policy-makers have long argued that Information and Communications Technologies (ICT’s) have the potential to improve the quality of life for everyone. In recent years the development of technologies that support individuals in managing their health has become a vibrant yet challenging research area. Specifically there is a rising focus on the use of mobile ICT, both hardware and software to mitigate some growing healthcare issues. This is not surprising when looked at in the light of Gartner’s study (August 1, 2007) ‘Forecast: Mobile Services Worldwide, 2002-2011’ that estimates that the worldwide cell phone usage will top 3.5 billion connections by 2008.

This research focus is a result of an ongoing healthcare revolution that aims to shift the locus of responsibility of healthy living from the healthcare provider to the healthcare receiver. [9] The transformation in doctor and patient attitudes towards health and healthcare and their respective roles provides many opportunities to shift the focus of technology in healthcare from just supporting clinical professionals in delivering high quality care to allowing and encouraging lay individuals to adopt increasingly proactive roles in caring for themselves. Of all the diseases that can be prevented by such active engagement of the affected individual, diet related conditions have the most to gain from. Studies have shown that 1/3 of patients take all the medicines prescribed to them, 1/3 take some and 1/3 don't take any at all. The levels of non-compliance to medical dietary advice are even higher.

3 Goals

The broad research goal for our group is to empower individuals to make healthy food choices from amongst the available food service facilities near them. In doing so we hope to reduce the burden of diet related chronic diseases like type two diabetes mellitus and coronary artery disease from society. Our approach to this problem is to try and solve it at its source; that is the intersection between the healthcare and the food service industries. We are using a mobile device application that we have developed to work at this intersection. Amongst other things, the Pervasive Healthy Diet Adviser provides its users with the nutrient data of each individual item on the menus of the food service facility near them using peripheral ambient displays. This is made possible after analyzing the nutritional information databases of respective food chains and applying information visualization techniques to represent contextually relevant information from them to the consumers.

We hope that by displaying this information using appropriate metaphors we would enable our users to make healthy diet choices and incorporate this practice in their lifestyles. This information will not fall into the framework of any specific medical recommendation but will allow the user to choose a healthy diet based on the framework that the user desires. One specific goal for our group at this stage is to find most inclusive metaphors to represent nutritional information of foods using ICT's. We aim to segregate such metaphors based on various user characteristics into categories, which are most effective for specific population groups. The metric that we have chosen to labels such a "best fits" is the acceptance of these metaphors by individuals and their consequent ability to encourage behavioral transformation.

4 Methodology

In order to abstract nutritional information using the PHDA we undertook the following steps:

1) We collected the nutritional information databases of food service facilities which were freely available over the internet. We used the information from McDonalds, Burger King, Subway, Chik Fil A, Taco Bell and Pizza Hut for the purposes of our research. The rationale behind this choice was our overarching research goal of reducing the burden of diet related chronic diseases by helping individuals make better choices while eating out. Researching popular fast food takes our study closer to our target population.

2) The nutritional information provided by these facilities was convoluted and hard to comprehend. It was not possible to apply it directly to our research. We then processed each of these databases to extract the calorie and the macronutrient information for each item on their menu. This information was then converted from unusable metrics like "grams of fat" to more practical measures like "the percentage of energy derived from fats". Another problem that we found with this information

Nutrition Facts	Serving Size	Calories	Calories from Fat	Total Fat (g)	% Daily Value**	Saturated Fat (g)	% Daily Value**	*Trans* Fat (g)	Cholesterol (mg)	% Daily Value**	Sodium (mg)	% Daily Value**
Sandwiches												
Hamburger	3.5 oz (100 g)	250	80	9	13	3.5	16	0.5	25	9	520	22
Cheeseburger	4 oz (114 g)	300	110	12	19	6	28	0.5	40	13	750	31
Double Cheeseburger	5.8 oz (165 g)	440	210	23	35	11	54	1.5	80	26	1150	48
Quarter Pounder®+	6 oz (169 g)	410	170	19	29	7	37	1	65	22	730	30
Quarter Pounder® with Cheese+	7 oz (198 g)	510	230	26	40	12	61	1.5	90	31	1190	50

Fig. 1. Existing nutritional information

	Calories	**% Fat**	**% Carb**	**% Proteins**
Hamburger	250	32.4	49.6	19.2
Cheeseburger	300	36.0	44.0	20.0
Double Cheeseburger	440	47.0	30.9	22.7
Quarter Pounder®+	410	41.7	36.1	23.4
Quarter Pounder® with Cheese+	510	45.8	31.3	22.7

Fig. 2. Processed nutritional information

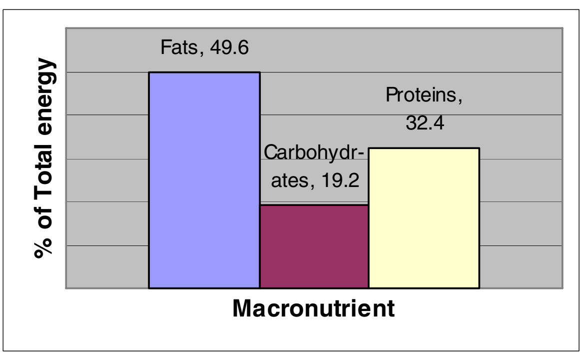

Fig. 3. % energy from macronutrients for Hamburger

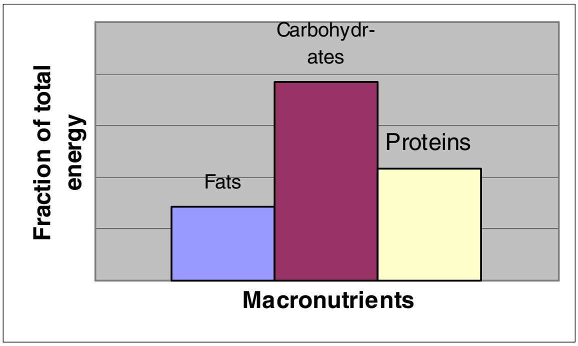

Fig. 4. % energy from macronutrients for Hamburger after normalization

was the calculation of % Daily values based on a 2000 Kilo calorie reference diet. We believe that in this age of ubiquitous computing we can embrace the concept of nutritional individualism and the use of a standard reference goes against that.

3) The processed information for each of the items for these food service facilities was then visualized using bar graphs.

4) On doing do we found that the concept of a balanced diet was hard to visualize using the conventional bar graphs that we had generated for this information. The nutritional recommendations for a balanced diet require that the % of energy derived from each macronutrient category be unequal in a particular proportion. Mayo clinic recommends that a balanced diet should contain 45-65 % carbohydrates, 10–35 % of proteins and 20-35 % of fats. [11] This information goes against the mental image that the word “balanced” construes in our minds. We believe that this is one of the major issues that hinder the success of peripheral displays in trying to represent nutritional information effectively. To avoid this evident pitfall we normalized the distribution of macronutrient representations by multiplying them with different factors. The end result of this intervention was that for the purposes of our research a balanced diet would now be represented by three equal macronutrient bars in a bar graph.

5 PHDA Design

PHDA is a distributed mobile device application that runs on the windows mobile platform. It allows the user to search for restaurants based on the calorie content of the food being served by them. As a result of this search the users are presented with a location based view of the restaurants around them. The restaurant logos are outlined in red or green borders depicting the results of the calorie based search. On selecting a restaurant the user is presented with the items from that restaurant’s menu. These results are also color coded using the same paradigm as above. On selecting a particular food item the user is presented with the numerical calorific value of that choice along with a metaphorical representation of its macronutrient balance. On selecting a particular food item its macronutrient representation is converted into the wall paper for the mobile device. In this manner that representation serves as a peripheral ambient display which helps the user in making future dietary choices.

Fig. 5. PHDA start up screen

6 Implementation Process

By relying on a User Centered Design approach, our group performed an extensive review to understand the context described in the introduction of this paper. This review led us to identify healthy nutrition as a curative intervention for those suffering from chronic diseases and a necessity for those trying to prevent these diseases. In this sense, the group identified a very broad user base that varies adequately in several dimensions: gender distribution, age, education, urban or rural lifestyle, religion, culture, cognitive abilities and professions. Taking into account that these dimensions are non-exclusive, we found that profiling the user base was a task of great complexity.

We also identified a considerable gap between the nutritional information that was provided by food service facilities and how well their consumers understood it. The problem was not related to the information not being available as it was made public through different sources like brochures in the restaurant, the food chains website and the National Nutrient Database for Standard Reference [10]. However, the information was not available to the users in a format that is easy to comprehend by them. It thus failed to have any useful impact on their food choices. We did not find any clear standards in place for presenting this data. In many cases, we noticed that the values were displayed in arcane terms like grams per serving or relative to amounts such as the recommended daily intakes that the users were not familiar with. Another related problem we observed was that this information was available in a generic manner for all the users. This further precluded any possibility of it being useful as the concept of a balanced diet is a dynamic and personalized one. On exploring the issue further, we realized that in order to render this information useful the users needed it to interact with their current nutritional state.

Fig. 6. PHDA User Interface

To bridge this gap we have turned our research towards devising graphical interfaces that provide ambient displays using appropriate metaphors to help people understand the nutrient contents of the food being consumed by them in food away from home scenarios. This information will empower the user to understand how adequate certain nutritional choice is for their individual goals (keep their condition in check, weight loss or weight gain) and to quickly recognize which elements of their diet are the most inadequate, and require attention and alternatives. For this purpose we have started a series of focus groups with participants of different ages and backgrounds in which we go over several dimensions of the user and build metaphors (with their corresponding graphics) that can be used to cater to users that differ in:

1. Physical attributes: gender, age.
2. Perceptual abilities: hearing, vision.
3. Cognitive abilities: memory span, literacy and reading level, math skills.
4. Physical spaces: sound levels, lighting, computing platforms available.
5. Cultural and international diversity: languages, information flow, symbols.
6. Special populations and disabilities.

The designed metaphors were simple to comprehend and were specific to locale of United States [fig.]. The next step in the implementation process was the developing of prototypes to evaluate the usability of the metaphors. We developed peripheral

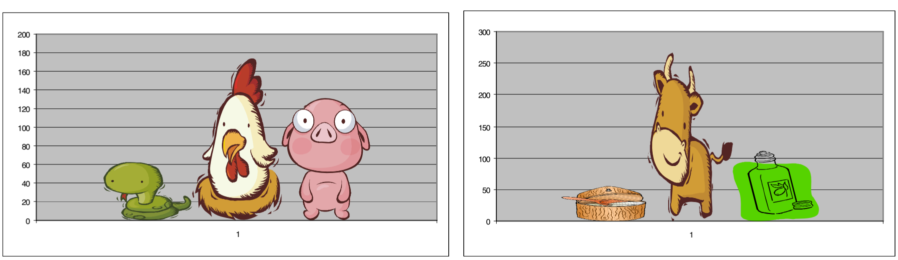

Fig. 7. Metaphor for proteins, fats and carbohydrates

display on mobile interfaces and ran cognitive walkthrough study, which was followed by a heuristic evaluation using neilsen's heuristics in order to discuss the issues concerning the usability and mapping issues of these peripheral images to the dietary concerns of individuals. In one of our displays, we used the metaphor of bread for carbohydrates, cow (beef) for proteins and butter for fats. We hypothesized that the mapping of the dietary habits with these contextual entities would help the user in understanding the importance of the information.

In order to complete the cognitive walkthrough we had a working prototype of a peripheral ambient display images as backgrounds of mobile devices. It was done to gauge the user's response to the ambient display in a mobile setting. We also we wanted to know how these pictures could map on to the dietary guidelines for the individuals. The prototypes were designed to simulate user experience, as the subject would have while using such a nomenclature in next age menu design, mobile health indicators and peripheral orbs. The users were asked to look at the display and tell the examiner the following aspects of the prototype

a) If the diet associated with the display is balanced or not?
b) Do these symbols or displays give enough cues, as to what they mean?

The users of the study were a group aged between 21-40. A sub-group consisted people who had some basic knowledge about dietary facts and the other sub group consisted of people who had no knowledge of facts like importance of fats, proteins and carbohydrates in a balanced diet.

Fig. 8. PHDA Interface

Major emphasis was getting the feedback from the user as to what such peripheral devices mean to them. This 'meaning' is essential in altering the behavior of an individual over a period. The study focused on the following questions

A. Are the assumptions about what the display is supporting correct given the user's experience and knowledge up to this point in the interaction?
B. Will users see the peripheral ambient item, for example, a cow on a background of a mobile display

C. It is one thing for a display item to be visible, but will the user's know that it is the one they have a memory mapping to comprehend information?
D. After the information is taken, will it be enough to modify their behavior patterns over period of time?

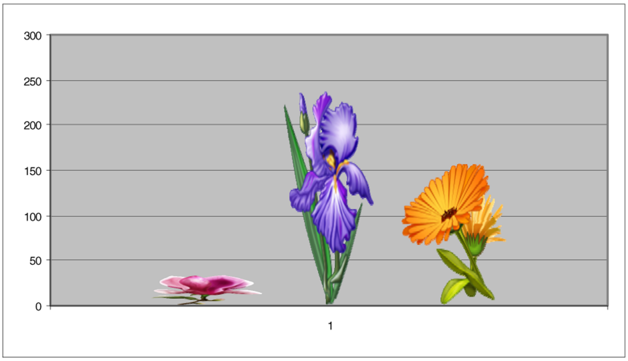

Fig. 9. Flower Metaphor

7 Results

The cognitive walkthrough opened a new realm of relationships between user's understanding, context and mapping to actual parameters depicts in such peripheral displays. The sub group, which had little or no knowledge about dietary elements, had a mental model of a balanced diet as a balance of depicted entities irrespective of what these entities meant. Thus, any three figures normalized to depict a balanced nutritious content was good enough mental model for them. The sub group, which had prior basic knowledge about nutritional facts could relate to the metaphors like cow, butter and bread to the nutritional value. The imbalances in the size of these entities signified the imbalance in the nutritional content. The focus group resulted in understanding the user space and the concerns. The sessions are yet to be transcribed but the overall picture seems to support the hypothesis that people can relate to such peripheral displays with the nutritional facts easily as compared to numbers.

8 Conclusion

The results confirmed that the user could relate these peripheral display images with the nutritious content of a given food item. The power of preventive medicine and ubiquitous computing is used to build a diet advising application PHDA in order to help its users choose a healthy diet. Specifically, we discussed the fidelity of different mobile device based peripheral displays in abstracting nutrient data of the food, served in food chains around the country. We would implement the knowledge gained in this exercise to create new experiences in food item menus, mobile nutrition detector, health based menu display. Thus, our work will continue in this sense to build a stronger map of metaphors and take advantage of multimedia and connectivity to data sources provided by many of the computing platforms available to users today.

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Intelligent Assistive Exoskeleton with Vision Based Interface

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Abstract. This paper presents an intelligent assistive robotic system for people suffering from myopathy. In this context, we are developing a 4 DoF assistive exoskeletal orthosis for the upper limb. A special attention is made toward Human Machine Interaction (HMI). We propose the use of visual sensing as interface able to convert user head gesture and mouth expression into a suitable control command. In that way, a non-intrusive cameras control is particularly adapted to disabled people. Moreover, we propose to robustify the command with a visual context analysis component.

In this paper, we will first describe the problematic and the designed mechanical system. Next, we will describe the two approaches developed for visual sensing interface: head control and mouth expression control. Finally, we introduce the context detection for scene understanding.

Keywords: Rehabilitation robots, Face detection, Head gesture interface, Lips extraction, Context analysis.

1 Introduction

Researches in handicap field are trying to model the incapacity and attempt to develop aids in order to compensate the motor, sensorial and even cognitive deficiency and give more autonomy to deficient people.

In this perspective, we are developing an assistive technology for people suffering from myopathy, able to assist the upper limb movements. Myopathy is a neuromuscular disease in which the muscle fibers do not function, resulting in muscular weakness. This project is an industrial project of 2 years conducted between differents partners[1] and consists in developping an innovative 4DoF assitive exoskeletal orthosis. The system designed will compensate for the loss of mobility in the upper limb, especially for joints of the shoulder and elbow. The potentiel users are defined by the following criteria:

* Corresponding author.

[1] AFM, LISV, Poincar hospital, Techinnovation, CEA.

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 123–135, 2008.

- remaining gripping capacity equivalent to at least a claw
- a shoulder movement rated at least 3 out of 4 (experimentaly measured by the AFM and based on MFM [2].

Even if some adjustment is provided, it is still hard for disabled people to use the joystick to operate the assistive technology although they can move their bodies. To deal with this difficulty, we present visual sensing as a possible solution.

In this context, we propose an original Human-Machine Interface based on a monocular camera that controls a 4 axis assistive exoskeletal orthosis. We present two methods: head gesture control using face detection and mouth expression control. However, visual sensing interface should be performed without significantly disturbing the primary function of the mouth/head. The gesture of the user (head movement and mouth expression) should not be exclusively used for control command since it might cause an ambiguous command. In fact, the system must be able to switch automatically from a command mode to a non-command mode when the activity of the user involves head and mouth movements. We propose then to incorporate context detection for scene understanding approach and thereby avoiding confusing command. In this paper, we will first describe the problematic and the designed mechanical system. Next, we will describe the two approaches developed for visual sensing interface. The final part will be devoted to the context analysis approach.

1.1 Problematic and Intended Application

During the last years the rehabilitation technology is developing towards more flexible and adaptable robotic systems. However, orthosis systems for upper limb are not suitable, expensive and do not target the real need of disabled people. This project emerged from different reflections and user's specifications. The main requirement is to develop a light, discreet orthosis that does not impose but assists the movement of the user (Fig. 1). Therefore, we have investigated in an intelligent HMI. To detect the gesture of the user, there are two main solutions:

- Wearable interfaces
- Camera based interfaces

The first works in wearable interfaces dedicated to disabled people are mainly developed for the control of an autonomous wheelchair. Jaffe [5] describes a system based on ultrasonic sensors, mounted at the wheelchairś head-rest that senses the userś head position.Y.-L. Chen and al. [13] propose a tilt sensor module that is attached to the back of the userś head. With the help of two integrated inertial sensors, the overall device interprets two-dimensional head movements and subsequently triggers an appropriate translational or rotational motion of the wheelchair.

[2] Mesure de Fonction Motrice pour les maladies neuromusculaires (www.mfm-nmd.org)

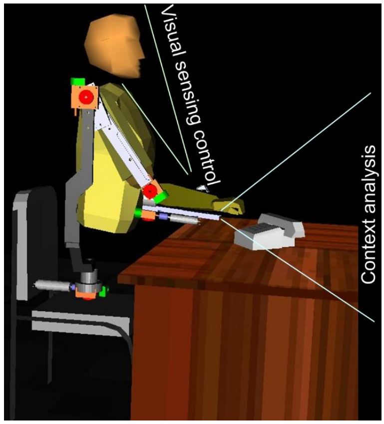

Fig. 1. Four axis assistive exoskeletal orthosis model

However, this kind of interface is not very convenient to use since it requires a specific installation and uses body-contact devices (ultrasonic sensor[6], magnetic sensors, accelerometers). Therefore, visual sensing seems much more convenient to use since the interface based on camera is a non-contact and non-constraining interface.

Many works are trying to integrate the camera to get the user gestures. MIT CSAIL [11] developed a head interface for dialog box confirmation and document browsing using a stereo camera. They have also described an additional context learning component which exploits interface context to obtain robust performance.

We present two approaches:

- Head control using planar face detection: the control consists in detecting the head movement and extracting a suitable control command. Two approaches have been tested. The first detects the face in the 2D space whereas the second provides pose estimation by a 2D-3D correspondence problem. Adaboost[12] and PosIt[1] are the key algorithms used.
- Mouth expression control: the control by mouth expression is an innovative proposal that suits people with severe disability with no significant head movement. The control is the result of expression classification obtained by an analytical modeling of the lips.

Moreover, we integrate a context analysis component to avoid confusing command understanding. In fact, the orthosis system should be able to switch automatically from a gesture based command to a manual command (joystick) depending on the context.

1.2 Mechanical System Description

The exoskeletal orthosis has been designed to compensate for the loss of mobility in the upper limb especially for joints at the shoulder and elbow. The specifications were developed by the AFM and concern mainly the architecture, the control command, security and energy consumption. Actually, the system should be compact and aesthetically socially acceptable. The movement and the command are also compelling issues. The user should be able to reach all the neighboring space. For the shoulder, two movements are possible: the abduction and flexion and for the elbow there is the flexion-extension and the prono-supination (Fig. 2). Biomechanical testing on people with muscular dystrophy were conducted and permitted to classify them into 4 groups according to their residue of movement. The system should be then able to be adaptable enough to fit the user according to his group. In fact, despite users in the group 3 and 4 who still have some mobility, people in the group 1 and 2 lose completely the use of their muscle and are able to move only their fingers. The system designed is composed of 4 joints (Fig. 3). We have developed a complete forward and inverse geometric solution as well as a kinetic resolution. In order to decipher the inverse kinematics of the robotic manipulator, the Denavit-Hartenberg (D-H) convention is used. The D-H parameters are found by assigning a local reference at every joint as shown in 3. Let $\theta_1, \theta_2, \theta_3, \theta_4$ be the D-H parameters, table 1 shows the DH table computed from a simplified model of the orthosis.

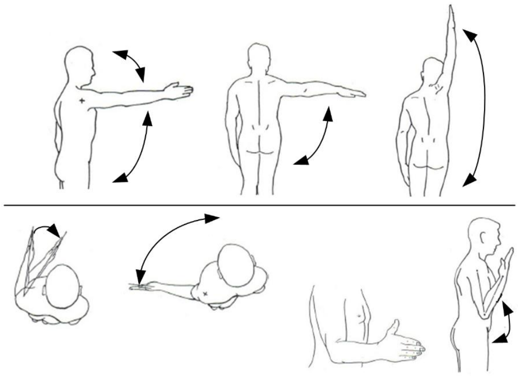

Fig. 2. Overview of the possible movements

Table 1. D-H Parameters

J	α	d	θ	r
1	$\pi/2$	h	θ_1	0
2	0	0	$\theta_2 + \pi/2$	$-L_b$
3	$-\pi/2$	0	$\theta_3 - \pi/2$	0
4	0	0	θ_4	L_{ab}

The choice of actuators was based on the fact that the orthotic system should bear a weight of at least 3 kilograms. There are two main families of actuators

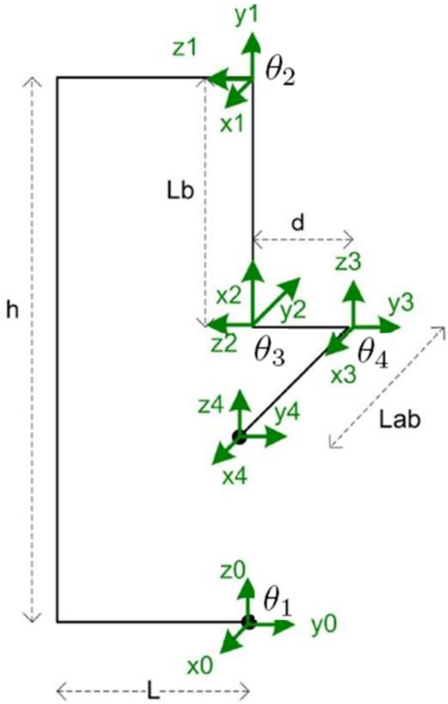

Fig. 3. Coordinate systems for D-H parameters

in robotic orthosis: activation through rotating motors and through pneumatic muscles. Pneumatic muscles have the advantage of being closer from humans muscles architecture than rotating motors, but such pneumatic systems are still very massive and more complex to integer in the mechanical system. In the opposite, rotating motors are compact and easily incorporated in the orthosis. For our system, we have chosen DC brushless motors for their higher efficiency and reliability. Brushless DC motor is a synchronous electric motor which is powered by direct-current (DC) and which has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes.

2 Intelligent Camera Interface Approach

Because of disability, usual interfaces are very complex to use. Visual sensing presents a possible solution since head gesture and mouth expressions are natural gestures commonly used during face-to-face interaction. Moreover, camera is a discrete interesting sensor that does not need any special installation from the user.

Unlike people belonging to class 3 and 4, people in class 1 and 2 do not have enough residual movements and can not then move their heads thereby using the head gesture interface. Therefore, we investigate in mouth expression control which can be used either as a complementary interface or as an independent one.

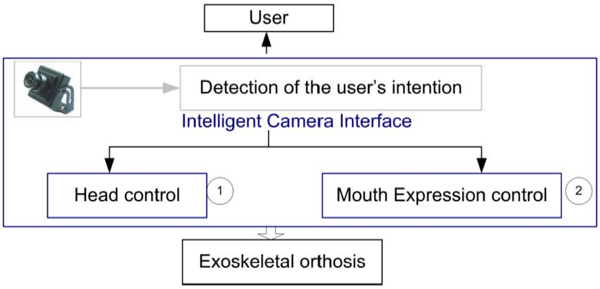

Fig. 4. Intelligent Camera Interface concept: (1) the first algorithm (2) the second algorithm

In this section, we will describe the two approaches (Fig. 4). The first one uses the global head motion whereas the second one used local face expressions to control the exoskeleton system.

2.1 Head Control

The principle of this approach is to track the head movement and extract a control command for the orthosis using a monocular camera. The most challenging part of the design is the development of a robust automatic face and feature detection.

The first algorithm extracts a mono directional command based on the planar face detection. According to the motion, the end point of the orthosis is moved along one cartesian axis. This step allowed us to validate the robustness of the face detection algorithm but is not sufficient for the targeted application since the orthosis is moved along only one axis.

We built up then our thinking to a three dimensional face tracking. Pose Estimation is determined by a model based approach using a 3D/2D feature point correspondence. The pose estimation returns the rotation and translation matrix of the head from which the control command is obtained. Fig. 5 shows an overview of the head control approach. The algorithm proposed is based on a hierarchical analysis of the image. There are two steps:

attention region,
face detection and global feature extraction.

The attention operator is applied in order to minimize the execution time by the minimization of the search region. The search of the attention region is very important since it allows rejecting up to 50% of sub-block images. This attention operator is based on the cross-correlation technique. The problem turns then into a pattern matching problem. Adaboost test is then applied to detect the faces and then the eyes in each accepted sub-block. Adaboost is the most recent face detection method with both high accuracy and fast speed [12]. It extracts the Haar-like features of the image, which contain the image frequency information

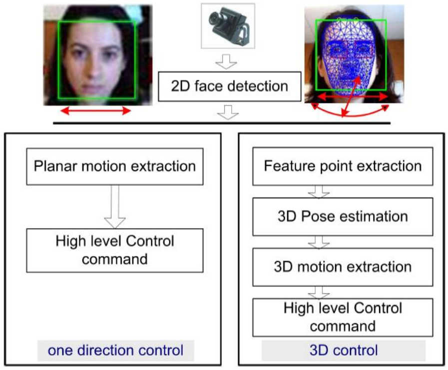

Fig. 5. Face motion control

only by integer calculation that is fast. Then a set of key features are selected from all the extracted features. After being sorted, this set of features are used as a cascade of classifiers. Afterward, we minimize the wrong detections by a test of coherence. This test consists in validating the detecting blocks if two eyes were detected. Otherwise, the block is assuming wrong.

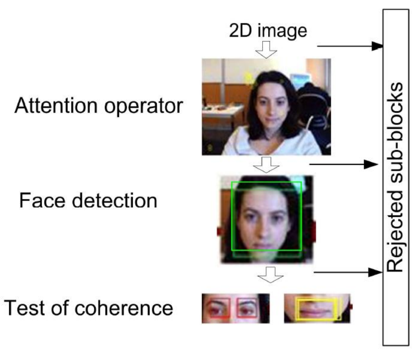

Fig. 6. Hierarchical face detection overview

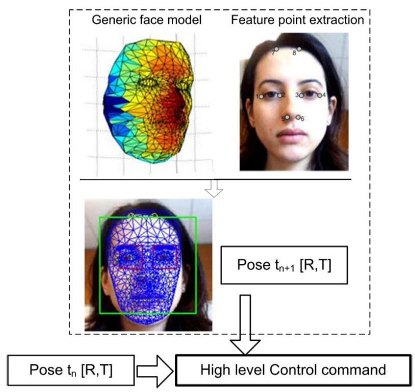

Fig. 7. 3D head control overview

Fig. 6 shows an overview of the proposed face detection algorithm. Once the 2D face detected, a mono directional control command can be generated. For a 3 dimensional command, the head motion is estimated by a 3D/2D feature points correspondence [7] using a generic 3D model of the face.

Feature points extraction is based on human visual characteristics. The feature points detected are: the eyeballs, the corner of the eyes, the nose points and brow. For locating the feature points, we should set the searching areas of the points firstly. Eye region are found automatically by Adaboost. The other regions are then determined using the geometric relation between the features. Once the searching region located, we apply a common technique to estimate automatically the feature points which is based on the property of the valley point [4]. The iterative PosIt algorithm [1] is then used for pose estimation. High level command is induced for the 3 axis by analyzing the time evolution of the transformation matrices (Fig. 7).

2.2 Mouth Expression Control

Mouth expression control is based on mouth extraction and expression modeling and classification (Fig. 8). To each class of expression corresponds a command instruction. Various techniques have already been proposed to extract visual information associated with the mouth and are classified in three main families.

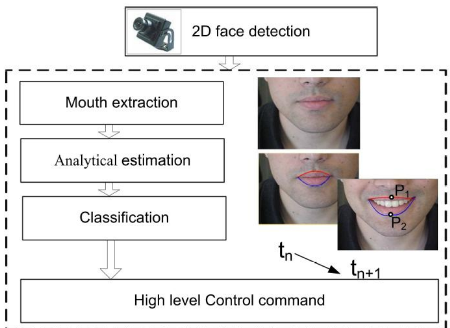

Fig. 8. Mouth expression control

The low level methods (Segmentation, Classification) [10] use only the information contained in the texture of the image. They suppose that the characteristics of the lips' pixels are different from those of the face. The average level methods (Active contours) [8,2] use both the information of the images and the constraints of regularity. The high level methods (Analytical deformable models, Active forms),[9] are based on characteristic models of lips, obtained through heuristics or statistic ways.

The algorithm is based on the colorimetric approach. It assumes that the characteristics of the lips' pixels are different from those of the face. It is then possible to separate them from the other pixels, by thresholding. The first step is to convert the RGB image space into YIQ. The representation of the luma information shows one or two dominant peaks, which represent the lips (if the mouth is opened, the two peaks are separated). Thresholding the image is done to isolate the lips from the remaining parts of the face. The threshold is automatically calculated from data estimation using a Gaussian model. The model of the lips is then computed by using the least square algorithm with two second order polynoms. The classification is then done by computing the sum of the radius of curvature of each curve estimation as in equation 1

$$C = \frac{2a_1}{(1-(2a_1P_1+b_1^2)^{3/2}} + \frac{2a_2}{(1-(2a_2P_2+b_2^2)^{3/2}} \quad (1)$$

where

- $a_i, b_i, c_i, i \in 1, 2$ are the coefficient of the polynom for the upper and lower lip,
- P_1 and P_2 are key points (see Fig. 8)

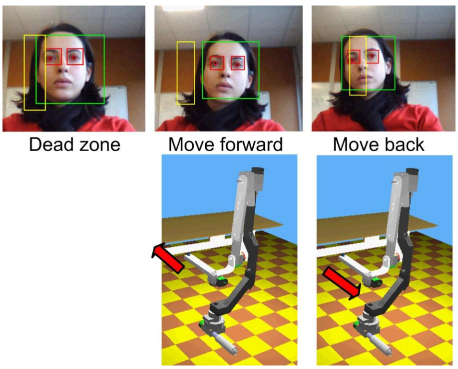

Fig. 9. Head control HMI: (top) face detection, (bottom) system movement

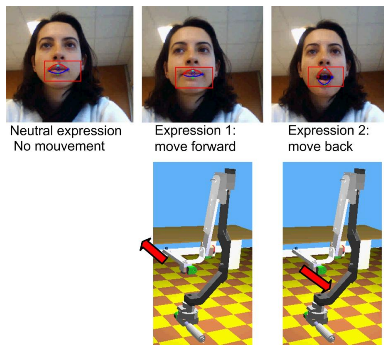

Fig. 10. Mouth control HMI : (top) mouth detection and modeling, (bottom) system movement

Fig. 9 and 10 show the result of head control HMI and mouth expression HMI. In the next section, we will describe the context analysis component.

2.3 Context Analysis

The gesture interface provides a suitable interface for disabled people according to their degree of disease. However, confusing command could occur when using head or mouth expression control.

We have then investigated in environment context analysis which exploits the environment of the user to obtain robust command. There are several sources of potential errors with a gesture based interfaces. For example when the user is speaking or interacting with someone, his face/mouth movements may be interpreted as a control command. To avoid these types of false positive interpretation, we draw up a context analysis component that detects and extracts moving objects from background and then switches automatically from the vision based control to a manual one (Fig. 11). The idea is to use background subtraction technique for segmenting moving objects in the scene. Given a frame sequence

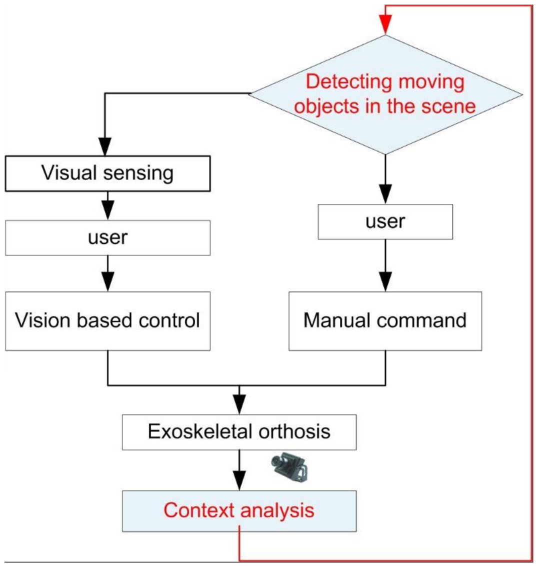

Fig. 11. Context analysis approach

from a fixed camera looking to the environment of the user, the goal is to detect all the foreground moving objects and then switch the command mode. Basic methods tackle this problem by computing frame difference by the mean of thresholding.

Let I_k be the incoming frame and B_k the background frame. The pixels are assumed to contain motion if the absolute difference exceeds a predefined threshold level. However, the background image is not fixed and must adapt to illumination changes, motion changes (camera oscillation), etc. Therefore, it is necessary to update the background image frequently in order to guarantee reliable motion detection. The developed component for context analysis uses Heikkila and Olli algorithm [3] which consists in adapting the current background image using a first order recursive filter.

The background is updated following equation 2.

$$B_{t+1} = \alpha I_t + (1 - \alpha) B_t \tag{2}$$

where α defines an adaptation coefficient. The value of α is determined empirically. Fig. 12 shows the evolution of the result of background extraction by varying α. We note that α cannot be chosen too small because it may form artificial "tails" behind the moving objects.

In our approach, α is chosen equal to 0.6 and the update process based on Equation 2 is only indented for adapting to slow changes in overall lighting.

The idea of the context analysis component is to detect moving objects in the environment (in front of the user) and then to switch from the automatic control mode if a person is moving in front of the user. To detect if the moving object is

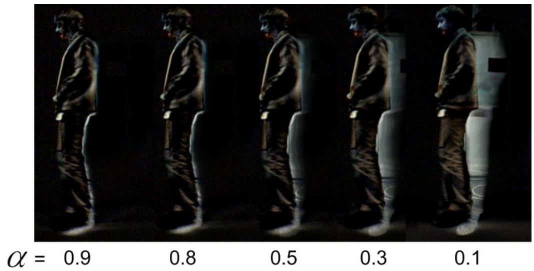

Fig. 12. Results of background extraction : evolution function of α

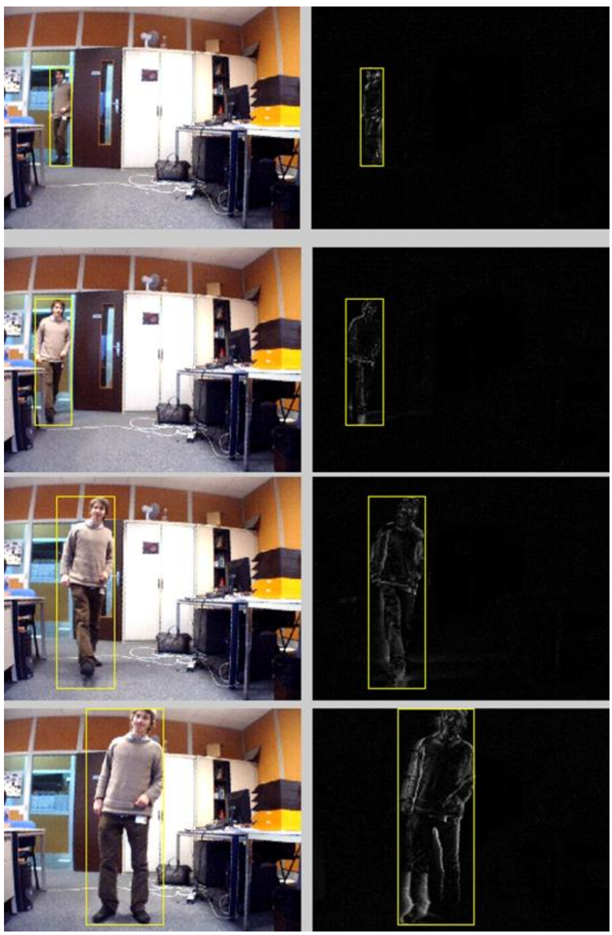

Fig. 13. Background extraction and human detection

a person or not we compute the ratio between the width and the height of the bounding box. Fig. 13 shows some results of this approach.

3 Conclusions and Future Works

This paper presents a camera based human machine interface for a 4Dof assistive exoskeletal orthosis using context environmental analysis. The system is designed for people suffering from myopathy resulting in muscular weakness. The main requirements consists in developing a flexible and adaptable robotic system and therefore a special attention was made toward human machine interaction.

In that context, we developed vision-based head/mouth movement interface components to allow simple user interface interactions. We explored two approaches of perceptual interface components. The first uses global head gesture. Based on image processing techniques and learning algorithm (Adaboost), the face motion is used to extract a suitable control command. The second approach considers the movement of the mouth, and is destined to people belonging to class 1 and 2 of the pathology. The classification of the analytical model of the lip allows estimating the control command.

A context environment analysis is developed based on background subtraction technique to avoid ambiguous command. The context analysis extracts moving objects in the environment of the user and switches the mode of control of the orthosis to manual.

As future work, we plan to develop a more complete context analysis. Based on stereo system, we plan also to add a pose and gaze point estimation thereby estimating the attention of the user. Moreover, we plan to do a set of experimentation on the real orthetic system which is being manufactured by our partners.

Acknowledgments

The authors gratefully acknowledge the contribution of National Research Organization and reviewers' comments. The authors express their thanks to the A.F.M.(Association Francaise contre les Myopathies) and Poincar hospital (PlateForme des Nouvelles Technologies) for their cooperation and their collaboration for the well going of this project.

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Assessment of the Impact of Sensor Failure in the Recognition of Activities of Daily Living

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Abstract. Smart Homes offer improved living conditions and levels of independence for the elderly population who require support with both physical and cognitive functions. Within these environments sensing technologies provide a key facility to monitor the behaviour of the person and their interactions with the living environment. In this paper we investigate the effects of sensor failures on the 'trust' of activity inference processing. We introduce a sensor evidence reasoning network which has been developed for ADL recognition along with the ability of handling uncertainty that may occur at a sensor level. Details of the initial experiments which have been conducted in the assessment of ADLs in a smart laboratory environment using this model are presented. Finally, we present the findings from the analysis on experimental and simulation data taking into consideration the impact of sensor failure on the overall stage of inference processing.

Keywords: Smart homes, activities of daily living, sensing technologies, evidence fusion, trust.

1 Introduction

Smart Homes which have the ability of integrating sensor technologies and intelligent information management systems have emerged as potential solutions to facilitate the desired requirements associated with 'aging in place'. The sensing technologies provide a means to acquire data about the inhabitant's movement and interactions within the home environment [1]. This data is then processed through an intelligent information management system which makes recommendations as to how the environment should be adapted to support the needs of the user [2]. As such, sensors provide the fundamental low level data which forms the basis of how the smart home is able to provide assistive living conditions and improved levels of independence for its inhabitants. The main concern is therefore that the data obtained from sensors within the home environment may not be totally reliable and may present different degrees of uncertainty in the measurements they report [3]. This uncertainty may arise for a number of reasons. For example, it may be the case that the sensor is faulty or

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 136–144, 2008.

malfunctioning, it may be that it can never be 100% accurate due to the nature of what it is measuring (e.g. fine grained proximity measurements) or it may be that the overarching management system has for some reason corrupted the data. In our work we have aimed to investigate the impact of sensor uncertainty within smart homes and the means by which such uncertainty could be accommodated for. We have focused on the deployment of anonymous binary sensors including movement detectors, contact switch sensors, and pressure mats in the monitoring of the Activities of Daily Living (ADL) in Smart Homes. In our previous work [4] we have developed a sensor evidence reasoning model for activity inference which can aggregate evidence from multiple sensors along with the ability of handling uncertainty that sensor evidence may bear with. We have extended upon these theoretical concepts to investigate the notion of 'trust'. Trust is one of the major practical limitations which can be related to the actual deployment of technology within smart homes. In this paper we investigate the notion of trust of data processing in smart homes and the possible effects of sensor failure in relation to activity recognition.

2 Evidential Approach of ADL Recognition

Due to the constraints of building a Smart Home, such as privacy, cost, technical installation of retro-fits and practicability anonymous binary sensors have been well accepted for monitoring ADLs such as preparing drinks or meals, interacting with household objects for example the telephone or television and personal hygiene related activities. Binary sensors can not directly identify people and at any given time may only present one of two possible values as an output. Whenever the state of a certain context (object, movement) associated with a sensor is changed, the value of the sensor is changed from '0' to'1' and hence represents the fact that it has changed from a static state. Typical types of binary sensors include passive infra red movement detectors, contact switches and pressure mats. Movement detectors can be used to detect user presence throughout the house. Contact switches may be installed on the doors of appliance objects such as cupboards, fridges and microwaves to detect the opening and closing of the objects. They may also be installed on doors into various rooms within the house and can therefore augment information provided by movement sensors. Several studies [5-8] have been undertaken in the area of activity monitoring through the deployment of sensing technology, similar to that described above, to detect interactions with objects. Nevertheless, there has been little exploration of the trust of the proposed activity inference processing systems and the impact which may be caused due to sensor failure. The challenges posed with the use of sensor technology and the determination if a sensor provides a value of 'on' or 'off' how sure can we be about this measurement are huge. By applying Evidence Theory for the representation and management of sensor uncertainty may provide a possible solution to this problem. In our current work we have proposed an approach of activity inference based on sensor evidence that also provides a way to control the quality of the underlying inferring process.

2.1 Evidence Theory

Evidence theory, of which Dempster-Shafer theory [9] is a major constituent, is a generalisation of traditional probability which allows us to better quantify uncertainty [10]. It provides a means of numerically representing our belief on the value set of a variable in the form of a mass function. The exhaustive set of mutually exclusive values that a variable can hold is called the *frame of discernment*, denoted Θ. For instance, a sensor denoted *s* can be in two states 'on' and 'off'. If we use '1' to represent 'on' and '0' to represent 'off'. Then Θ = {1, 0} is a frame of discernment for the variable *s*. The mass function distributes a unit of belief over Θ as follows:

(1) $m(\phi) = 0$, i.e. the mass function of the empty set ϕ is always zero;

(2) $\sum_{A \subseteq \Theta} m(A) = 1$, i.e. the sum of the masses of all the subsets of Θ is one.

The main difference between these definitions and conventional probability is that a mass value can be committed to either a singleton or a subset of Θ. Mass functions can be used to define the lower and upper bounds of the probability. The lower bound called the *belief* (*Bel*) represents the degree of belief in supporting *A*. The upper bound called the *plausibility* (*Pls*) describes the degree of belief on failing to refute *A*.

$$Bel(\mathrm{A}) = \sum_{B \subseteq \mathrm{A}} m(B) \text{ and } Pls(\mathrm{A}) = \sum_{B \supseteq \mathrm{A}} m(B).$$

The belief and plausibility can therefore be used to determine the amount of support on *A* and can be used to induce rules based on the mass allocations for various values and may be regarded as providing pessimistic and optimistic measures of how strong a rule might be [11].

One of the main advantages of Evidence Theory is that Dempster's rule of combination allows us to accumulate evidence from distinct sources. Let m_1 and m_2 be two mass functions on Θ. A new mass function m then is formed by combining m_1 and m_2 as:

$$m(C) = (m_1 \oplus m_2)(C) = \frac{\sum_{A \cap B = C} m_1(A) m_2(B)}{1 - \sum_{A \cap B = \phi} m_1(A) m_2(B)}.$$

2.2 Evidential Modelling of ADLs

Sensor data is usually highly dynamic and prone to noise and errors. For instance the contact switch sensor installed on a fridge door may have an intermittent technical problem. As such a zero reading does not necessarily mean that the inhabitant has not opened the fridge door. It may in fact be the case that the door has been opened, however, due to some malfunction the desired activation of the sensor has not been reported.

To detect an ADL we need to identify the individual stages involved with the activity. For example, consider the ADL of 'preparing a simple drink'. Within this activity it is possible to monitor a person's behaviour and assess if they are either preparing a cold drink or a hot drink. If it is the latter it is possible to categorise this further to establish if the drink is tea or coffee. It is therefore possible to identify the necessary actions involved with the preparation of each drink. Once these have been identified the actions can be mapped onto an array of sensors which would be required to monitor and distinguish which activity is being performed. Table 1 provides details of the seven sensors which are required to assess the ADL of preparing a simple drink.

Table 1. Summary of sensor technology used for the ADL of preparing a simple drink (O – optional, Y – yes, N – no)

	Sensor Name	*Description*	*Tea*	*Coffee*	*Cold Drink*
1.	Fridge sensor (fri)	Detects if the fridge is opened	O	O	Y
2.	Cupboard sensor (cup)	Detects if a cup or glass is removed from the cupboard	Y	Y	Y
3.	Coffee sensor (cof)	Detects if coffee is taken	N	Y	N
4.	Tea sensor (tea)	Detects if tea is taken	Y	N	N
5.	Sugar sensor (sug)	Detects if sugar is taken	O	O	N
6.	Water sensor (wat)	Detects if the taps on the sink are turned on.	O	O	N
7.	Kettle sensor (ket)	Detects if water is poured from the kettle.	Y	Y	N

In our previous work [4] we proposed evidential networks of activity inference on the basis of activated sensor evidence. Lower level activities can be used to deduce higher level activities where the lowest level activities are inferred from actions revealed by sensor evidence. Fig. 1 shows four examples of evidential networks of activity inference based on this concept. Fig. 1(a) and (b) show the networks of inferring activities 'Making drink' and 'Grooming' based on lower level activities. Fig. 1(c) and (d) are the inference networks for activities 'Making cold drink' and 'Making hot drink' which are based on sensor information.

In Fig. 1 a circular node represents a sensor, a square node represents an object, and a rectangular node represents an activity. An eclipse node contains all objects which are considered to be compulsory to perform an activity. A compulsory object or sub-activity is linked to an activity through the intermediate eclipse node or directly by a line with a solid diamond end. On the other hand, a line with a hollow triangle end represents lower level nodes which are alternatives to the higher level nodes. A square node connected to an activity rectangular node by an arrow-headed line represents an object that is optional i.e. it may or may not be involved in performing the activity. A dashed line represents an evidential relationship.

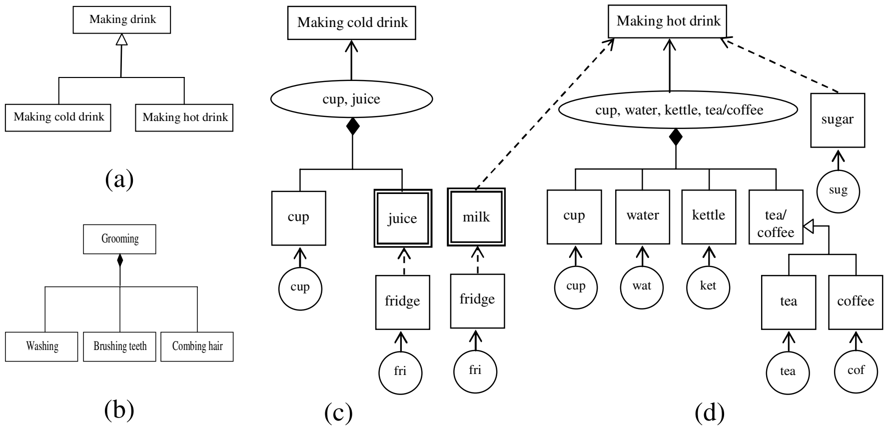


Fig. 1. Inference models for activities of (a) making drink (b) grooming (c) making cold drink and (d) making hot drink. Fig (a) and (b) represent inferring activities based on lower level activities whereas Fig (c) and (d) are inference networks based on sensor information.

3 Methods

To test our theoretical concepts we undertook a series of experiments within our laboratory based smart environment. This is an engineering based laboratory which provides a platform to evaluate technological solutions prior to their deployment within real living environments. This environment offers a kitchen area along with a living/dinning area within which experiments may be conducted. Fig. 2 provides an indication of the plan layout of the entire room showing the divide between the Smart Lab and a desk based research area along with snapshots taken in the kitchen area.

Each time a sensor is activated its ID along with a time stamp is stored in a database. To assist with future experiments within the lab, in addition to openly sharing our data with others within the research community, we have developed an XML based schema. This schema, referred to as homeML [12] can be used for the storage and exchange of information recorded within smart environments. It is hoped that by adopting such an approach the heterogeneous nature of data recorded within smart environments may be overcome. In addition, given the XML based nature of this approach the data representation becomes system/application/format independent.

The experimental set-up as described above was in operation for a period of 4 weeks. During this period people's interaction with the devices in the kitchen environment were recorded as they prepared simple drinks on a day to day basis. Over this period of time a total of 58 recordings were taken. Each recording comprised of a record of all activities for an instance of preparing a simple drink, along with the time of each sensor activation. In addition, each recording was supplemented by a video recording. This permitted an off-line analysis of the data to verify the sensor recordings for each experiment along with the name of the activity which was being performed.

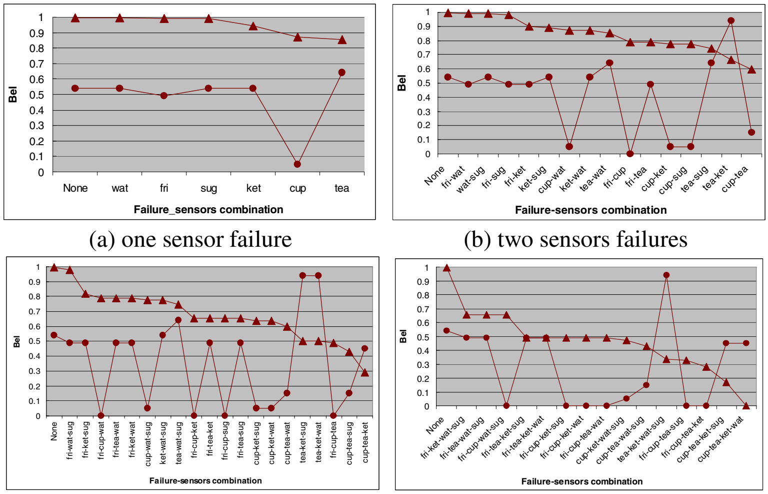
Fig. 2. Overview of the smart environment used for testing (a) plan view of entire room layout showing split between the kitchen and living area and a research desk based area (b) detailed design view of entire room layout (c) picture taken within the kitchen environment (d) picture of coffee jar with the sensor (e) picture of kettle and water tap with the sensors

4 Results

To analyse the data from the 58 recordings the sensors activations were presented to the evidential reasoning program on a case per case basis. The results following the off-line analysis of the sensor activation data have shown that 100% accuracy has been achieved in correctly detecting all of the different drinks which had been prepared in the aforementioned 58 recordings.

Following validation that the model itself was correct from both a theoretical and practical perspective the issue regarding the reliability of the sensor information was further investigated. The question which is to be asked is ‘if a sensor provides a value of ‘on’ or ‘off’ how sure can we be about this measurement and what impact does it have to the overall classification of the ADL’. In an attempt to address this question we examined the failures of reporting sensor activations in relation to their impact on the belief value assigned with making a decision.

Consider performing the activity of ‘Making hot drink’ and in particular ‘Making tea’. The sensors and their involvement in this activity have previously been presented in Table 1. The activity ‘Making Tea’ can be inferred through the detection of the set of six activated sensors: *cup*, *tea*, *ket*, *wat*, *fri* and *sug*. To investigate the impact of failure to report sensor activations on our evidential inference network and the decision it would infer we varied the number of sensors which were considered to have failed. Fig. 3 shows the belief changes in the overall inference of ADL assessment associated with the number and different combinations of sensor failures.



(a) one sensor failure (b) two sensors failures

(c) three sensors failures (d) four sensors failures

Fig. 3. Beliefs (*Bel*) on 'Making hot drink' (triangle dotted lines) and 'Making cold drink' (circle dotted lines) when there are (a) only one sensor (b) two sensor (c) three sensor and (d) four sensor failures

This situation allows us to examine the impact on the proposed model of dealing with sensor failure in instances where ADLs are actually being performed. Among the six sensors the four sensors (*cup*, *tea*, *ket*, *wat*) are associated with the objects that are compulsory in terms of the ADL whereas the two sensors (*fri*, *sug*) are optional i.e. they may or may not be involved when making tea. Fig. 3 reveals there is a notional threshold of belief degree at 0.6, above which we can always achieve the decision of 'Making hot drink (tea)' which is correct. The only one exception to this rule is witnessed in Fig. 3(b) when *tea* and *ket* are the two failing sensors.

Fig. 3(a) shows that when only one sensor has failed, i.e. the sensor's activation is not detected and hence it is not possible to say whether it has been activated or not by only observing it in static status, our inference model is credible to distinguish 'Making hot drink' by having the greater belief degree on 'Making hot drink' (always above the value of 0.80) as opposed to suggesting 'Making cold drink'. From Fig.3(b) it can be observed that when two sensors are considered to have failed the model is trustable most of the time except when the two sensors which have failed are *tea* and *ket*. In Fig. 3(c) when three sensors have failed the model is trustable as long as two out of the three failed sensors are not both compulsory sensors or are both compulsory but one of the two compulsory sensors is not *tea*. Given that sensor *wat*'s role is partially complementary to sensor *ket* in the model, they can be seen as performing the entire role together. This explains why when the compulsory sensor *cup*, *ket* and *wat* are broken the model can still function correctly. When the number of failed sensors increases to four out of six the model is almost unable to work with only three cases satisfying the threshold given above as shown in Fig. 3(d). With the situation of 5 and 6 sensor failures the model becomes totally unreliable.

5 Conclusion

Within this work we have investigated the effects of sensor failure/reliability on the trust of activity inference within the domain of ADL assessment. This study has addressed an important issue within the realms of sensor management within smart homes and has taken the initial steps to put in place an infrastructure which can deal with unexpected sensor failures. The early experimental results have been encouraging. We have tested our model on a series of experiments conducted within a smart environment and under ideal conditions (i.e. no sensor failure) we have been able to achieve 100% correct classification of all 58 recordings taken. Our evidential approach is capable of correctly determining the activity performed when all sensors are fully operational. It can also be sustainable to combinations of up to 3 types of sensor failure. The future work which we have planned will include 1) online implementation of the approach, 2) incorporation of temporal information of sensor activations in activity inference and 3) integration of prompting aids to support the inhabitant independently managing daily living activities.

Acknowledgements

The authours are grateful for the support provided by the Nestling Technologies Project to undertake this work.

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Keeping Elderly People at Home: A Multi-agent Classification of Monitoring Data

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Abstract. We propose software architecture to monitor elderly people in their own homes. We want to build patterns of monitored people dynamically from data about activity, movements and physiological information. To obtain this macroscopic view, we use a multi-agent method of classification: every agent has a simple skill of classification. They generate partial partitions and cooperate to obtain a set of patterns. The patterns are used at a personal level, for example to raise an alert, but also to evaluate global risks. These data are dynamic; the system has to maintain the built patterns and has to create new patterns. Therefore, the system is adaptive and can be spread on a large scale.

Keywords: meta-monitoring, dynamic classification, old people's patterns, multi-agent system.

1 Introduction

Industrial countries will be confronted with aging populations in the coming decades [1].

A possible strategy to resolve partially this difficulty is to encourage old people to be cared for in their own homes. This strategy presents two main advantages:

- The elderly want to stay at home as long as possible; they keep the privacy they do not want to lose.
- It is less expensive than a place in a collective accommodation.

Our project takes place in this context. It aims to help professional home care teams in their job by increasing the number of elderly people looked after in their homes with an adaptive and non-intrusive remote assistance.

Contrary to existing systems in the home care domain [2] [3], which are user-centered systems, our approach tackles the home monitoring issue in a more global way. We collect individual monitoring with the aim of merging global behavior patterns. Patterns of monitored people could also be used to estimate the status of someone in relation to their community or to integrate new comings.

We propose a system able to carry out a generalization of profiles' patterns and to propose a classification of monitored people. An agent watches over one or more

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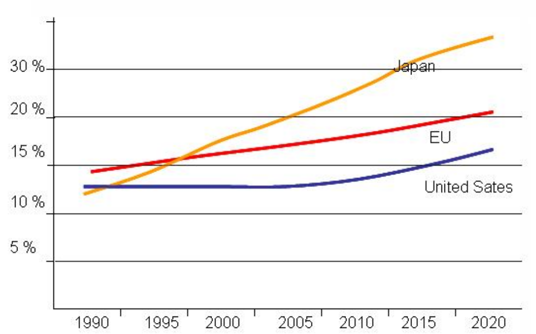

Fig. 1. Population aged 65 and over (% to the total population)

indicators of a group of people. An indicator is data about daily activities, positions and physiological information. In a first step, the agent applies a local classification method and obtains an incomplete patterns' partition. Next, the partial partitions are compared each other in order to build a complete classification. We conceived an open system: new people or/and new indicators bring in new agents or/and new patterns.

In the next Section, we present the architecture of the system and its functioning.

2 The S(MA)^{2}D Architecture

S(MA)^{2}D (Multi-agent system for keeping elderly people in their own homes) is a multi-agent framework in which agents use a restricted cooperation protocol to collectively perform classifications.

2.1 Architecture

The system is based on a bunch of sensors carried by monitored people or installed in their homes. Those sensors are for example presence and movement sensors or medical measuring apparatus [4]. The data coming from sensors are transformed into indicators. These indicators will be used by the system to generate its classification. Note that the functioning of the system is independent of the type and the number of these indicators.

S(MA)^{2}D is the multi-agent architecture; this distributed approach proved their adequacy in many health problems [5]. The system manages several classification agents which collect indicators. Because the system is strongly distributed, indicators of two people can be collected by different agents. There can also be some overlaps, if several agents collect the same information.

Thus, classification agents A_j have indicators i_k concerning several individuals P_i (Figure 2).

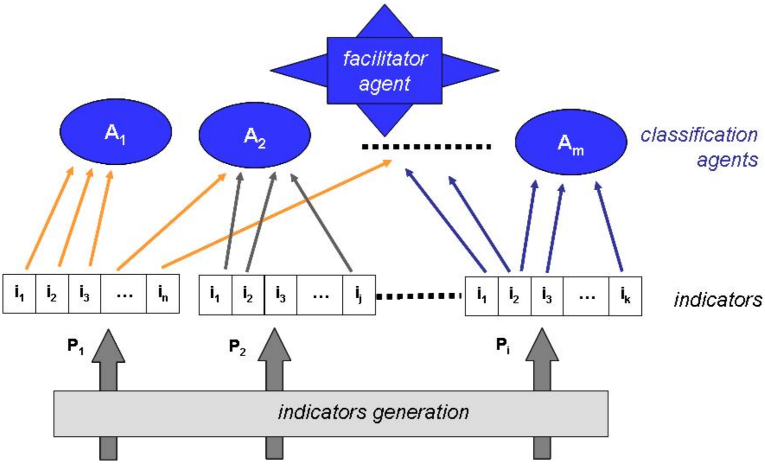

Fig. 2. S(MA)^{2}D architecture

This classification is multi-agent because it is really a collective work and not the work of a simple agent, as it is the case in other multi-agent systems (choice of the most skilled [6]).

The system has two essential characteristics. The first is the dynamic evolution of classifications – if needed, new data and new indicators can be added at any moment, and the system is able to reconfigure its classes and generate new classification patterns. The second is that the system is generic with respect to indicators and thus is able to function on any type of applications having strongly distributed entries.

2.2 A Detailed Example of Functioning

With its indicators, each agent calculates a local, partial classification. Since the data input are numerical values, any statistical classification method is applicable. These values can be normalized by several methods as:

1. Normalization between [0.1]

$$\tilde{I}j = \frac{I_j - I_j^{\min}}{I_j^{\max} - I_j^{\min}} \qquad (1)$$

where $I_j^{\min}$ (resp. $I_j^{\max}$) is the minimum value (resp. maximum value) of indicator number j.

2. Linear normalization

$$\tilde{I}j = \frac{I_j - \bar{I}_j}{\sigma_j} \qquad (2)$$

where Īj is the average values of indicator number j for a given agent, and σ_j is the standard deviation of indicator number j for a given agent

$$\sigma_j = \sqrt{V_j} \text{ and } V_j = \frac{1}{n}\sum_{k=1}^{n}(I_j^k - \bar{I}_j)^2 \quad (3)$$

V_j is the variance of indicator number j for a given agent; n is the number of people monitored by an agent; I_j^k is the indicator number j of the person number k.

Thereafter we apply our proposal on an example of 3 agents, 3 behavior indicators, and 11 people. Suppose I_1 is the body temperature, I_2 is the number of getting up/sleeping in one night, and I_3 is the number of entries to the toilets for a day.

The following table shows the distribution of people (P_i) and indicators (I_j) between the agents of the system (A_k).

People \ Indicators	I_1	I_2	I_3
P_1	**A_1**	**A_1**	--
P_2	**A_1**	**A_1**	--
P_3	**A_1**, $\underline{A_3}$	**A_1**	$\underline{A_3}$
P_4	**A_1**	**A_1**, *A_2*	*A_2*
P_5	**A_1**	**A_1**, *A_2*	*A_2*
P_6	$\underline{A_3}$	*A_2*	*A_2*, $\underline{A_3}$
P_7	--	*A_2*	*A_2*
P_8	--	*A_2*	*A_2*
P_9	$\underline{A_3}$	--	$\underline{A_3}$
P_{10}	$\underline{A_3}$	--	$\underline{A_3}$
P_{11}	**A_1**, $\underline{A_3}$	**A_1**, *A_2*	*A_2*, $\underline{A_3}$

Fig. 3. Distribution between the agents

The table of Fig. 3. shows that agent A_1 monitors two indicators I_1 and I_2 of people P_1, P_2, P_3, P_4, P_5 and P_{11}. Agent A_2 monitors two indicators I_2 and I_3 of people P_4, P_5, P_6, P_7, P_8 and P_{11}. A_3 monitors two indicators I_1 and I_3 of people P_3, P_6, P_9, P_{10} and P_{11}.

This table also shows that people do not have the same indicators (it will often happen in real situations). For example, P_1 has only two indicators because for this person it is not necessary to test the number of entries to the toilets. The aim is that each person has the indicators suited to his case.

We assume that the sensors send data to the system on a daily basis. In reality there are indicators that are more important than others, for example body temperature is more important than the outside temperature, so we give a weight for each indicator; this weight will help us later to form the groups of agents and to calculate the distance between classes. The most important indicator will be the one with the largest weight. In our case we give to I_1 (body temperature) the weight 3, to I_2 the weight 2 and to I_3 the weight 1 (which is the default value).

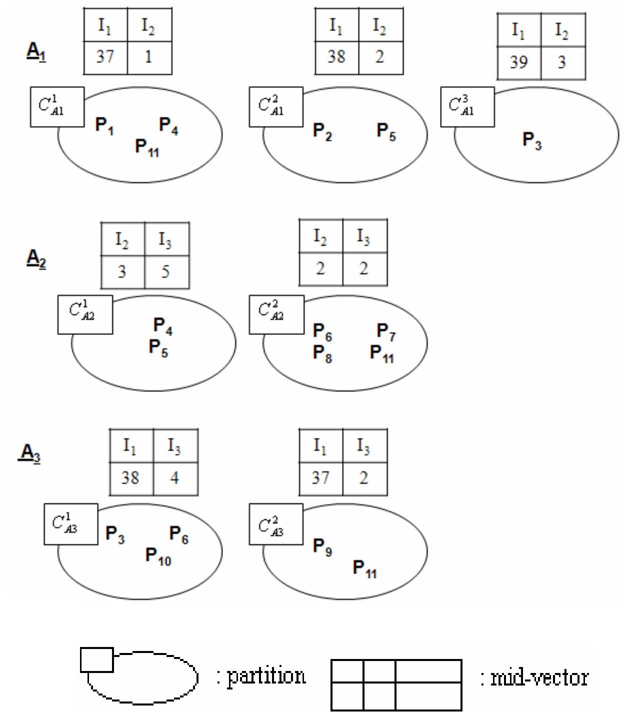

Fig. 4. Preliminary step: construction of partitions

By applying a local classification method (for example ISODATA [7]) each agent builds its partition. A mid-vector calculated by ISODATA characterizes each class.

To refine these partial classifications, the agents cooperate. They congregate in acquaintances network according to the similarity of the produced partitions. More precisely, each agent seeks the other agents, which made a classification close to one's own.

To compute the classes of the collaboratively determined partition, we designed a restricted cooperation protocol in three steps: call for participation / acquaintance's group constitution / multi-agent classification.

In the first step, the agents form groups to generalize the classification. The agents of the system communicate each other through the facilitator agent. The process to constitute agents groups for each agent A_i is:

1. A_i sends its indicators to other agents;
2. A_i receives the indicators from other agents;
3. For each other agent, A_i calculates the sum of the weights of common indicators (called S_1), and the sum of the weights of non-common indicators (called S_2);
4. If $S_1 > S_2$ A_i responds to the agent concerned;
5. The agents of a group are agents who have exchanged messages between them.

In our case, A_1 sends I_1 and I_2. A_1 also receives from A_2 and A_3 their indicators.

We find:

$$A_1 \cap A_2 = I_2$$
$$A_1 \cap A_3 = I_1$$
$$A_2 \cap A_3 = I_3$$

As the weight of I_1 is greater than I_2 and I_3, A_1 chooses A_3 to form a group. The result is two groups of agents. The first group is formed by A_1 and A_3, and the second is formed by A_2.

This second step is the acquaintance's group constitution.

The third (and last) step is to generalize the classification. The agents of a group measure the distances between their classes using the weighted Euclidean distance.

$$d_w(c,c') = \Big(\sum_{1\le j\le n} w_j.(d_j(c,c'))^2\Big)^{1/2} \tag{4}$$

where *c* and *c'* are two classes, w_j is the weight of the indicator number j, n is the number of common indicators between the two classes, $d_j(c, c')$ is the distance between the two mid-vectors of *c* and *c' according* to the indicator number j.

We can apply this formula on the actual values or normalized values of indicators. In this example, the agent A1 seeks to each of its classes, the closest classes of its group among other agents.

Calculation of distances between classes:

$$d_w(C_{A1}^1, C_{A3}^1) = \sqrt{3}\ ;\ \boxed{d_w(C_{A1}^1, C_{A3}^2) = 0}\ ;\ \boxed{d_w(C_{A1}^2, C_{A3}^1) = 0}$$
$$d_w(C_{A1}^2, C_{A3}^2) = \sqrt{3}\ ;\ d_w(C_{A1}^3, C_{A3}^1) = \sqrt{3}\ ;\ d_w(C_{A1}^3, C_{A3}^2) = 2\sqrt{3}\,.$$

After the calculation of distances, we find that the class C_{A1}^1 should be merged with C_{A3}^2, and C_{A1}^2 should be merged with C_{A3}^1. By contrast C_{A1}^3 should not be merged with C_{A3}^1 because there is another class from A_1 nearest to C_{A3}^1.

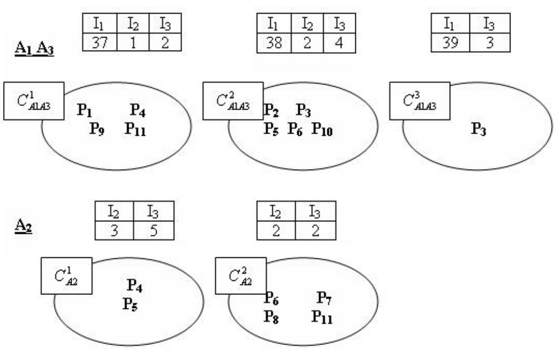

Fig. 5. Result of the classification

The new classes thus obtained have new mid-vectors, which are the averages indicators values on people belonging to a same class.

A person may belong to several classes according to the indicators used. For example, P_3 is classified by A_1 and A_3 in a class by itself according to I_1 and I_2, and it is classified with P_2, P_5, P_6 and P_{10} according to I_1, I_2 and I_3.

As prospects, we intend to set a minimum threshold for the distance between classes. This threshold will be based on indicators and their weights. If the distance between two classes is greater than this threshold, they will not merge, even if they are close in the sense described above. It will be a more true-to-life approach.

There may be several groups of agents. They constitute parallel classifications: they are views of the same monitored people but according to various criteria. The management of the monitored people continues throughout the functioning of the system, as the agents collect more indicators values. Thus, patterns evolve and the class of people can change. An indicator can also be deactivated: it corresponds to a data, which it is not essential to monitor for this type of people.

3 Conclusion

We chose to tackle the home monitoring issue in a more global way rather than in an only individual-centered way.

This large scale and global solution requires setting up a strongly distributed and dynamic system. Because classical classification methods are not adapted to this context, we had to propose a new distributed classification method.

To evaluate the performances of our system, we randomly generated a great number of numerical vectors of values and we observed the formation of classes.

Now, we have to define the real indicators to take into account. One of our professional partners CVital (platform of coordination of care and services to the person) is making a study about people whom this organism follows. This study will make it possible to define the number and the types of main indicators.

A collective vision of monitored people makes it possible to release patterns who will allow the system answering current health problems:

- Generate specialized alarms depending on the detected event. Once the classification is set up and people status is known, decisions can be taken to personalize the monitoring of someone - activated sensors, generated alarms and danger zone. A meta-monitoring will also make it possible to detect global problems. The migration of many people from a class toward another or the modification of certain characteristics of a class should indicate a collective event, which affects several people; this can happen, for example, during a heatwave or an epidemic.

- Find certain similarities with the existing tools for evaluating the dependence. Organizations of assistance to elderly people often use an evaluation grid of the dependence degree to determine the service needed by people. The use of our classification system will make it possible to see whether there is an adequacy between the evaluation of monitored people by the grid and the produced profile classes. The matching of the two evaluation ways would validate our approach but also could consolidate the relevance of the grid criteria. After validation, the system will be able to follow the evolution of the dependence degree of someone. Thus, somebody leaving his original pattern to enter a new one could be re-evaluated by the helper organization, and the assistance could be adapted to his new behaviors.

- Get global statistical data about old people looked after in their own homes. The possibility of having a global vision of several monitored people can bring richer and more relevant information on the follow-up; the distribution in classes and the historic of the patterns evolution should bring a better service to people entering the system. In particular, appropriate alerts according to the incurring risk should be generated.

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HESA: A Human-Centric Evolvable Situation-Awareness Model in Smart Homes

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Abstract. *Situation Awareness* is a paradigm that contains data gathering, logic reasoning and responsive interaction to capture situations, which describe system states, from dynamic environments. Focusing on evolvability issue, we proposes a generic *Situation Awareness System (SAS)* model, called *Human-centric Evolvable Situation-Awareness (HESA)*. In this paper, we present the HESA architecture, accommodation/evolution processes, and how we use Context/Situation Generation approach to provide human-centric fault-tolerant evolvability.

Keywords: Context/Situation Awareness, Context/Situation Generation, Evolvability, Fault-resilient, Human Intention.

1 Introduction

With the promise to ease and safe everyday life, pervasive technology is becoming more and more prevalent and accepted in society [1]. As one of the most popular pervasive technologies, Context-Awareness [2] was proposed in recent years to address the interaction issue. The essence of Context Awareness relies on the interaction between computer systems and environments. This new paradigm contains data gathering, logic reasoning and responsive interaction with the ubiquitous pervasive environment. Depends on the system's focus, Context Awareness might be called Situation Awareness. A Situation Awareness System (SAS) usually has an adaptable and distributed device framework consisting of sensor network and mobile computing techniques. SAS gathers data from the frameworks, extracts contexts from data based on predefined context syntax, and delivers proper services after certain logic reasoning.

The state-of-the-arts for SAS tends to focus on context modelling that usually utilizes logics and ontologies, context reasoning, and monitoring [4]-[7]. There exist several new design processes and architecture to efficiently develop SAS [8]-[10]. Many models or architecture have been developed for real world applications [11]-[14]. However, most of these approaches have limited capability in system evolution and involving human intention which is an important factor to pervasive environment. Smart Home is the target system of this research. It is featured as ever-changing environment. Its system behavior is heavily impacted by Human-Computer interaction driven by human intention. We identify four properties that must be possessed by Smart Home systems:

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 153–160, 2008.

(1) Context-awareness/situation-awareness. As discussed above, SAS naturally models the interaction between computer system and users.
(2) Evolvability. The SAS needs to adapt to the ever-changing ubiquitous environment, especially constantly changing user requirements.
(3) Human-centric. The human intention needs to be captured, modelled and seamlessly integrated into the software system. It drives system evolution.
(4) Fault-resilient. Frequent failure is a norm in the pervasive computing environment. Strong fault-resilient property is critical to any SAS system.

Focusing on these issues, we propose a human-centric evolvable situation-awareness system called HESA, which utilizes the new concepts of *context-generation* and *situation-generation*. The rest of this paper is organized as follows. Section 2 presents the rationale of this research. Then we describe HESA and its lifecycle in section 3. Section 4 presents two new concepts in HESA: Context Generation and Situation Generation. Finally, section 5 concludes the paper.

2 Rationale and Requirements on Situation Awareness Systems

2.1 The Ability of Evolution

Most existing SAS's model the pervasive environment as a closed system. In these systems, all the rules are predefined and are therefore hard to scale up. For example, situations (a higher level model defined as a collection of contexts that should be satisfied to invoke corresponding services) are usually specified at design stage. However, this design may not exhaust all the possible situations. Then at runtime stage, the SAS may not be able to make correct reactions due to missing specifications. We call the adaptation mechanism to this kind of runtime error (i.e. exception handling) as *Accommodation*.

In a wider view, SAS should not only adapt to moment environmental changes but also evolve to system-wide changes. Both the physical environment and human intention may change as time goes by. We call the adaptation to system-wide changes at the requirement level as *Evolution*.

We also identify fault-resilience and human participation as the key issues for achieving system evolvability.

Fault-resilient. Due to the heterogeneous nature of pervasive environment, frequent failure and unexpected situations are quite normal. To mitigate the consequence of failures and keep system functioning correctly, HESA provides three major solutions: improving data quality, designing powerful reasoning engine to deal with ambiguous or incomplete information at both context level and situation level, and providing dynamic adaptation at the application level.

Involving User Intention. One question has not been answered in this field very well: "What are the roles of human in the pervasive environment"? Exiting SAS's have weak involvement of *human intention*. As the recipient of services and the initiator of context-aware scenarios, the end-user drives the execution and evolution of SAS. Moreover, the requirements of SAS mainly rely on users' intention, which may constantly change. As discussed above, user requirements should be updated with the evolution of SAS. For this evolution, we need a generic model to capture and manage ever-changing human intention and a well-defined mechanism to integrate them into the system process.

2.2 A Smart Home Example

We use the following example to illustrate how human intention should be integrated into the system process and why the SAS should be evolvable. Consider a 78-year-old woman who lives alone and has difficulty to move around and turn on/off switches in each room. Smart Home Technology provides an automatic light system for her. Besides, a voice command system is implemented to control basic electronic devices such as TV set. Designers predefined all situations to turn on/off the lights and to utilize functions of TV. One predefined situation is described as "turn off the room light when the resident leaves the room". However, someday this old woman wants to keep the light on even if she already left the room. Unfortunately, this new intention is against the predefined requirements and system would not respond as what she expects. Then she has to struggle turning the light back on each time (supposing the system allows manual overriding). After living in this house for a while, she find it will be a great feature if the TV can be automatically turned on when she sits in front of TV - however this feature is not defined in the system.

In the previous example, an evolvable SAS should capture the user intention from her behavior pattern and reflect her intention in the system as follows:

Accommodation: After capturing the intention of "leaving lights on when leaving the room", our situation awareness system updates itself. Through this feedback loop our system evolves to another stage.

Evolution: Even if the system is automatically evolvable, it evolves in the controlled environment. The system design should be refined according to new requirements. A designer or an operator reviews system behavior and user responses. Based on the review comments, the designer elicits and updates system requirements. We call this process as evolution.

3 The Human-Centric Evolvable Situation-Awareness (HESA) Model

3.1 HESA Architecture

HESA architecture consists of seven layers: sensor layer, data fusion layer, context layer, situation layer, atomic service layer, service composition layer and human interaction layer. We describe the layers and our fault-resilient techniques as follows.

- Data components. Sensor layer collects data from physical sensor devices in a physical environment. Data fusion layer composes sensed data and measures its quality. We include a Data Quality Indicator (DQI) to compensate errors in data reading and hence improve data quality [15] [16].
- Logic-reasoning components. Context layer extracts context from sensed and fused data. Situation layer reasons situations from context. The two layers form logic components of HESA. They are modeled using interwoven ontologies. To handle faults such as configuration errors and decomposition errors in these layers, we propose *Context Generation* and *Situation Generation*.
- Service components. Atomic service layer and service composition layers deliver services to a user when a corresponding situation occurs. WS-Pro is a performance-driven service composition architecture [17] that manages high-level services and provides adaptation mechanism to service failures.
- Human Interaction Layer gathers data from human behaviors and guides decision processes such as context/situation reasoning and service invocation. Since human intentions pertains to human knowledge and wisdom structure, our intention ontology follows the KC process [3,18], i.e., Data, Information, Knowledge and Wisdom (DIKW).

3.2 System Evolution

The evolution of HESA starts from a set of pre-defined user requirements, based on which system designers create the first design. Then the system is implemented and deployed in the pervasive environment.

The HESA is human-centric, which means human intention plays a critical role throughout the life-cycle of the software system. In such a system, it is important to capture human intentions during the system execution and evolve the system accordingly. There are two steps in this feedback loop: inferring human intention from user responses (inference stage) and updating the HESA based on changed user intentions/requirements (evolving stage).

Inference Stage. The HESA acquires and stores the user's reaction and reviews. Based on this information, we infer user's intention in both automatic and manual ways. The automatic inference process is based on an ontology model. The output of this process follows semantics of ontology and is used for *accommodation*. The manual inference process is performed by system engineers to catch users' tacit and potential intentions. The output of this process is user requirements, which trigger *evolution*.

By including human intention to software lifecycle from design to deployment, we improve our understanding of requirements engineering and change the original closed system (ontology-based) to an open system (human intention guides updating of meta-rules in the original closed system).

Evolving stage. The capability to evolve differentiates HESA from other situation-awareness systems. With the ability to capture user intention, HESA can adapt itself and handle exceptions in both short-term (*accommodation*) and long term (*evolution*).

The accommodation is mostly focused on exception handling. With the input from ontology-based intention-inference-model, we update the situation ontology and context ontology. We provide context-generation and situation-generation functions during this procedure. Details are discussed in the next section. Accommodation is an automatic process conducted at run-time.

The evolution works at the level of system requirements. The DIKW model reasons user intentions and identify more sophisticated requirements. With the refined or newly created user requirements, software designers repeat the service-oriented design process and update HESA on the fly.

4 Context/Situation Generation

In HESA, *Context generation* is a mechanism to include future context to evolve and fault-resilient feature. *Situation generation* is a mechanism to handle unexpected situations.

We propose *Context generation* to deal with decomposition error and data error - the fault at context layer and data layer. The difference between context-awareness and *context generation* rests with the ability to include future context to evolve. This ability enables HESA to handle exceptions and to deal with incomplete context.

As we discussed earlier in this paper, context in HESA can indicate quality of data. During system execution, contexts might be missing or of low quality to be satisfied. We call these as incomplete context. We increase context quality for the low-quality case, and generate context when it's missing in the system. We always set its quality to low when we generate a missing context. HESA stores historical data of situations with context information if they had triggered invocation of services. The historical data are used for Context Generation. For example, if the type of missing context is temporal, then HESA might use historical data related with time to predict it. On the other hand, if it is quantitative context, HESA might conduct quantitative analysis of historical data to calculate a mean value for it.

We call a situation that is defined at design time as *pre-defined situation* and an unexpected situation that occurs during the system execution as *exceptional situation*. *Exceptional Situation* is a new requirement that is inferred with currently available context information from the predefined requirements. Exceptions may happen when (1) predefined situation cannot be satisfied because of incomplete context or (2) this situation is not pre-defined at design time. HESA generates exceptional situations to ensure the continuity of context reasoning and invocation of the desired services. If an exceptional situation is very similar to predefined situation, it becomes a valid exceptional situation, otherwise invalid.

One predefined situation can have several related exceptional situations. For example, situation *situA* is defined to be "Temperature *tempA* lower than 25", "Light Brightness *lightA* greater than 20", "someone is in room *rA*" and "someone is in *rA* is the most important factor". If situation *situA* is satisfied, service *servA* will be invoked. Based on this situation *situA*, we can find possible exceptional situations as follows:

`Exceptional Situation 1:`
tempA = **24**, **low quality** , *lightA* = 21, someone is in *rA*
`Exceptional Situation 2:`
tempA = **22**, **generated**, *lightA* = 25, someone is in *rA*
`Exceptional Situation 3:`
tempA = 23, *LightA* = **19 (high quality)**, someone is in *rA*

The exceptional situations 1, 2 and 3 do not exactly satisfy situation *situA*. However, these situations are very close to the predefined situation *situA* and may invoke services.

In addition, the following situation 4 is not an exceptional situation because the context "someone" and "Room *rA*" are critical and required to invoke the corresponding service.

`Situation 4:`
tempA = 20 (high quality), *lightA* = 30 (high quality), **nobody is in room *rA***

HESA translates situations into Vector Space. Because a situation consists of set of context and logic, there exist priorities among contexts in the situation. In addition, context itself has attributes such as context type, context name, context value, context quality, etc. Each context can easily be vectorized. Consequently, all predefined situations are saved as multi-dimensional vectors. If the current situation could not be found among predefined situations, HESA measures its distance from a predefined situation and decide whether it is close enough to invoke corresponding services based on vector similarity/clustering algorithms.

4.1 Relationship between Situations and Services

To provide *accommodation*, we use human intention to guide service invocation. We classify the relationship between services and situations as follows.

(1) At the pre-defined requirement stage, the set of service and situation are always connected. Human intention guides which services in the connected set to invoke.
(2) At the run-time stage, this connection may become temporally broken because pre-defined requirements may conflict to user's current intention. In other words, even if a predefined situation occurs, human intention decides not to invoke a related service. We call it an Undesired Situation.
(3) As shown in [1], a valid exceptional situation invokes a service. We call this situation a Desired Exceptional Situation. If one exceptional situation occurs frequently, HESA adds this situation into the predefined set. The following pseudo-code shows this flow of the decision process.

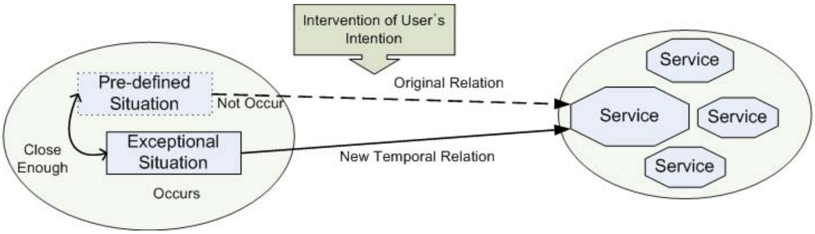

Fig. 1. Relationship between Situations and Services

```
If (the current situation satisfies a pre-define situation)
     or (it is close enough to one of predefined situation)
     If (user intention agrees to invoke the service)
           Choose a service among the set of related services
           Invoke Service.
     End If
End If
```

5 Conclusions

Though a new paradigm with promising features, pervasive computing still faces challenges in many areas. In this paper, we addressed the evolvability issue of SAS that embraces the other issues such as human participation, exception handling and fault resilient in ever-changing pervasive environment, and suggested a new generic model - HESA.

Targeting at SAS evolvability, we proposed a new architecture and process. We defined possible errors in each layer of SAS. We also presented the concept of context/situation generation. This concept enables SAS to be not only fault tolerable, but also evolvable in an autonomic way.

HESA uses inference ontology to show the possibility for inferring human intentions from contexts and situations, and to conceptualize intentions with contexts and situations of SAS. Human Intentions help updating system requirements, selecting a better service from a group, and triggering services even the current situation can not be recognized or satisfied.

Future work will be focused on the following; first, we will develop methods for capturing situations from user's responses and body conditions in the healthcare field; second, we will design the inference process of intention and emotion from the captured situations; third, we will also experiment the usage of the ontology to check whether invoked services follow user intentions or not; forth, we will develop a new requirement engineering process for the evolution to widely evolve SAS.

Another future work is to conduct field experiments to verify how the concept of context/situation generation works in the real-world situations.

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Sharing of Real-Life Experimental Data in Smart Home and Data Analysis Tool Development

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Abstract. Collecting smart environment experimental data in a real situation and sharing the data are necessary to make the technologies used in the smart environment more practical. We have developed a data analysis tool for the real-life experiment data collected in a smart home environment. The subjects of the 16-day experimental data were a couple of husband and wife in their sixties. The data analysis tool as well as the collected data with the consent of the subjects are open for the purpose of research and development. In this paper, we introduce how the data were collected and the outline of the data analysis tool to promote interdisciplinary research and standardization activities in the field of smart environments.

Keywords: Smart home, real-life experiment data, data analysis tool, real world deployment.

1 Introduction

Our society is facing two major issues: an aging issue and a global warming issue. For the former issue, we have to develop and deploy technical solutions to assist the elderly and to support their weakening in physical and memory abilities. On the other hand, the latter issue has come to the fore recently and has been recognized as urge action to decrease greenhouse gas emissions is needed in order to realize a sustainable society.

Advance of information and communication technologies (ICT) including sensor networking contributes to solve both of these issues. Smart environments where various kinds of sensors are embedded ubiquitously are able to detect real-world information including human behaviors and such information is often referred as context. Based on the information or context, services are constructed according to their respective purpose: to control actuators such as networked consumer appliances in order to increase convenience of usage or in order to save energy consumption, to notify people of wasteful energy use, to tell geographically distant extended family members about an unusual event that happens to

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 161–168, 2008.

an independent family member or establish a communication path between the extended family members and the independent family member.

Previously, plenty of efforts have been spent to establish fundamentals of research and development for realization of context-aware services on the basis of ICT. Therein experimental test beds are one of the important factors to promote the research and development and many trials have been done all over the world. As far as we know, the following test beds or projects are listed up; the Aware Home at Georgia Institute of Technology [1], the House_n group at MIT (the Massachusetts Institute of Technology) [2], Sensing Room at the University of Tokyo [3], EasyLiving project at Microsoft Research [4], the University of Florida's Mobile and Pervasive Computing Laboratory [5], MavHome project at University of Texas at Arlington [6], DOMUS laboratory at the University of Sherbrooke of Canada [7], UbiHome [8] and Active Home at Information and Communications University of Korea [9]. These test beds and projects contributed to the field of smart environments from the level of network architecture to the level of human-computer-interaction (HCI).

The research and development should be promoted not only by the efforts from researchers but also by collaboration with real users. Although it takes time and cost to collect experimental data in a real situation, they are necessary to make the technologies practical. The real situation means a natural and ordinal scenario and space where users can behave as they like. There are three Japanese projects whose results are open. The first one is the WTH (Welfare Techno House) where research on a smart environment and welfare tools for elderly or handicapped people was carried out [10]. People in the WTH were observed by using infra-red sensors and sensors to detect the status of doors and windows. Especially the activity of sleeping and toilet was detected well. The second one is an experiment carried out by AIST (Advanced Industrial Science and Technology) at the smart house Ikeda where one family spent their life for one month [11]. Their behaviors are recorded by 167 sensors of 15 kinds and are classified into 12 kinds of life actions automatically. The last one was the UKARI (Universal Knowledgeable Architecture for Real-lIfe appliances) project conducted by NICT (National Institute of Information and Communications Technology), 6 companies and 10 universities. In the UKARI project, they built a real-life test bed, called the "Ubiquitous Home," for home context-aware service experiments [13]-[15] and real-life experiments to collect the real situation data were conducted several times.

What is needed for the smart environment research to go further in the direction of practical use is to share the real situation data. Making the data open will produce new results. One is that there is a possibility to bring out new findings by analyzing base on an interdisciplinary viewpoint. The other is that we can clarify what is common and what is different among the groups of age, gender, nationality, race and so on. For the purpose of sharing the real situation data, we have developed a data analysis tool and started to distribute a set of real situation data. In this paper, we present the real-life experiment data and the data analysis tool.

2 Real-Life Experiment and Real Situation Data

NICT completed the Ubiquitous Home as a real-life test bed and conducted five experiments to collect the real situation data. At present, the fifth experimental data are open for a purpose of research and development only. The fifth real-life experiment was conducted for 16 days from January 14th to 29th, 2006. The subjects were a couple of husband and wife in their sixties. They used the Ubiquitous Home as it is like their own apartment. The experimenters did not invade their life except that there was an emergency call from the subjects because of device trouble. Their life records were recorded by various kinds of sensors including cameras and microphones. The type of each sensor is described in the followings. The size of experiment data is in Table 1.

Table 1. The size of experimenta data

Sensor Type	Data Size
Ceiling camera image data (JPEG image files)	1414GB
Ceiling microphone sound data (MP3 sound files)	1.9GB
Other sensor data	257GB
Total	Approx. 1.7TB

2.1 Image Data

Images were taken in every room using 17 ceiling cameras installed on the ceiling of the Ubiquitous Home. The arrangement of camera is presented in Fig. 1. Images are captured at $5 framessec$ in Motion JPEG format.

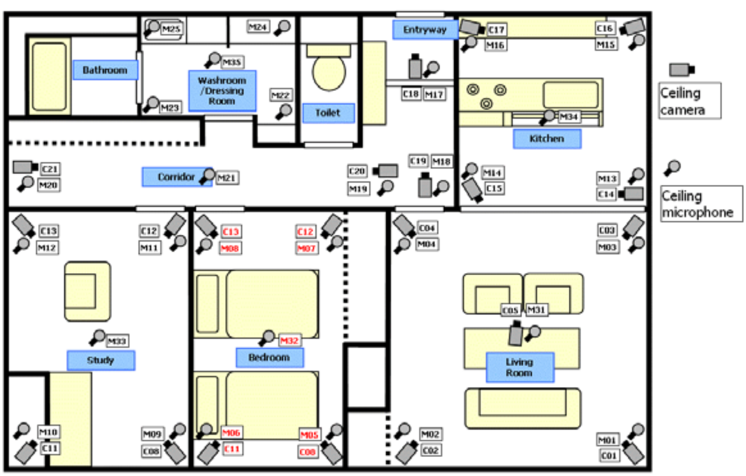

Fig. 1. The arrangement of ceiling cameras and microphones

2.2 Sound Data

Audio data from every room were recorded using 25 microphones installed on the ceiling of the Ubiquitous Home. The arrangement of microphones is also presented in Fig. 1. Audio files are recorded at one-minute intervals in 64 kbps MP3 format.

2.3 Other Sensor Data

The sensors used in the Ubiquitous Home are floor pressure sensors, infrared sensors, cushion sensors and sleep sensors. The position of these sensors is depicted in Fig. 2. The number of each sensor is in Table 2.

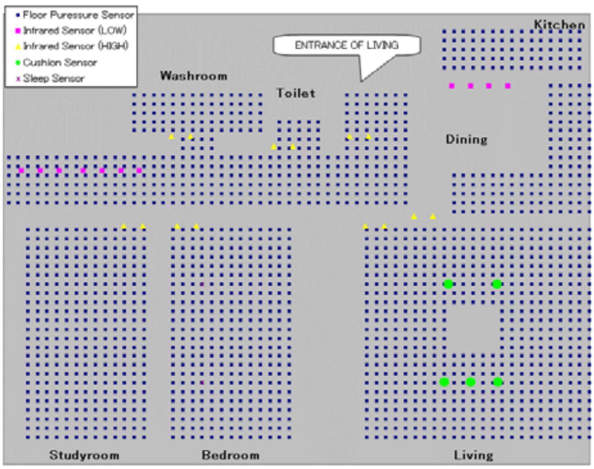

Fig. 2. The position of sensor elements

Table 2. The number of sensor elements

Sensor Type	Number of Sensor Element
Floor Pressure Sensor	1774
Infrared Sensor	28
Cushion Sensor	5
Sleep Sensor	2

Data from interface robots and electrical appliances installed throughout the Ubiquitous Home were also collected. The data from interface robots mean the dialogue data with the subjects and the data from electrical appliances mean the records of manipulation by the subjects. The electrical appliances include air conditioners, televisions, projectors, a washing machine and a refrigerator. The position of robots and electrical appliances is presented in Fig. 3.

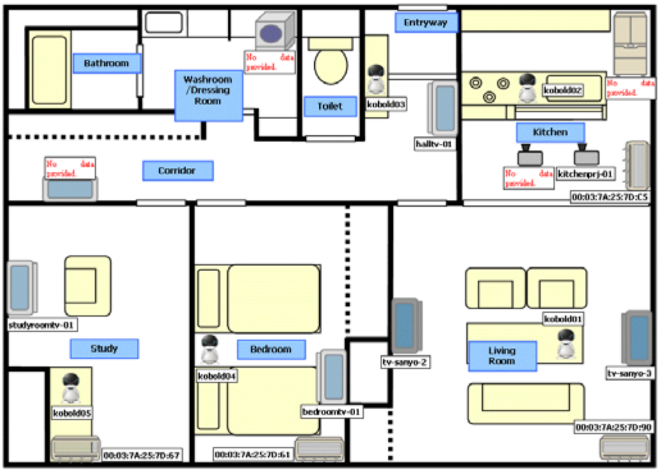

Fig. 3. The position of robots and electrical appliances

3 Data Analysis Tool

We have developed a data analysis tool (hereafter called the Analysis Tool) for visualizing and analyzing various sensor data, as well as image and audio information, which is recorded in the Ubiquitous Home. The Analysis Tool is comprised of two different applications: the Database Viewer and the UbiquitousHome Player. The Database Viewer is used to visualize and display the data from various sensors installed in the Ubiquitous Home (floor pressure sensors, infrared sensors, and so on). The UbiquitousHome Player is used to inspect and check the visual and audio data accumulated by the cameras and microphones installed in the Ubiquitous Home.

The Analysis Tool can be operated in a client-server system architecture. The system architecture is shown in Fig. 4. There are two kinds of servers: one is the HTTP server and the other is the Database server. The HTTP server is used to manage the image and sound data captured by the cameras and microphones and the data can be accessed by specifying the addresses in form of URL. The Database server is used to manage the various kinds of sensor data collected in the Ubiquitous Home. The sensor data are stored in a PostgreSQL database.

The Analysis Tool was developed using Microsoft .Net VisualStudio, and requires the Microsoft .Net FrameWork to run. In addition, because the Database Viewer accesses a PostgreSQL database, it requires a PostgreSQL ODBC Driver.

3.1 Database Viewer

In the Database Viewer, there are three different screens: the Display Screen, the Settings Screen, and the Filtering Screen. A user can select several functions such as Save, Filter, or Help from the menu bar on the Display Screen. On the Setting Screen, the user can specify which database is used, the server IP address

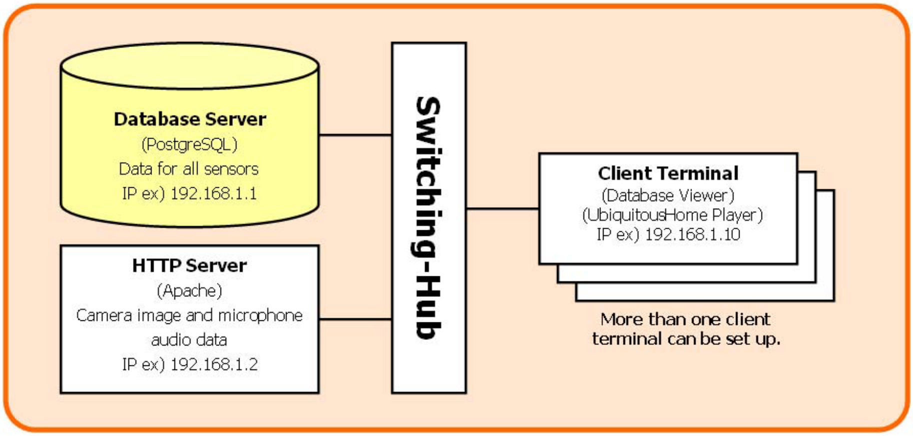

Fig. 4. The system architecture of the Analysis Tool

Fig. 5. The display image of the Filtering Screen for the floor pressure sensors

and port number to be accessed, or user ID and password. The Filtering Screen has a different setting screen for each kind of sensor. For example, the use can set data filtering for the floor pressure sensors by specifying the locations that the user wants to see. Figure 5 presents a snap-shot image of the Filtering Screen for the floor pressure sensors.

3.2 UbiquitousHome Player

The UbiquitousHome Player is an application to play the image and sound data stored in the HTTP server. In the UbiquitousHome Player, there are three different screens: the Display Screen, the Settings Screen, and the Selecting Screen.

On the Display Screen, the user can select the file to be open and operate several functions for the image and sound data such as changing the image size. The user can specify the server IP address and port number to be accessed from the Setting Screen. The Selecting Screen has four different screens: Date and Time, Camera, Microphone, and Speed. From these screens, the user can specify several items including the date and the time of the image, the camera number, the microphone number and so on. Since the user interface is based on GUI (Graphical User Interface), the user can manipulate the tool easily and intuitively.

4 Conclusion

The real-life experiment data were collected in a smart home environment and a part of data is open for the purpose of research and development with the consent of the subjects. Because of a variety of sensors and a huge size of data, a data analysis tool was developed.

The data and the data analysis tool can be shared with the researchers who like to use them for the purpose of research and development. It is desired that new findings from the view of interdisciplinary research will be brought out and standardization activities will be accelerated by use of the open data.

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Using Technology to Enhance Aging in Place

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Abstract. Integrated sensor networks have been installed in apartments of residents at TigerPlace, a retirement community helping residents age in place. Motion and bed sensor events have been logged continuously for over two years in some apartments. Using data from the sensor network, we have been investigating potential correlations to health events, such as falls, emergency room visits, and hospitalization, to identify patterns in the sensor data which might have offered some clues to predict the events. The long-term goal is to generate alerts that notify care givers of changes in a resident's condition so they could intervene and prevent or delay adverse health events. In this paper, two case studies are presented. In each case, the sensor network detected changes in the resident's condition that were not detected by traditional health care assessment.

1 Introduction

Older adults want to remain as active and independent as possible for as long as possible. They want to age at home, not in institutions like nursing homes [1]. The concept of aging in place is to allow seniors to remain in the environment of their choice with supportive services as needed [2]. With the help of community based services and supportive health care, the dream of aging in place is becoming a reality. Enabling technology, like low cost sensors, computers, and communication systems, has the potential to revolutionize health care services for older adults, promote independence, and enhance aging in place. Our research team is developing and deploying passive sensor networks in apartments of volunteer participants at TigerPlace, a unique retirement community built to help older adults age in place.

A primary goal of TigerPlace is to help the residents manage their illnesses and stay as healthy and independent as possible. To do so, we must help elders maintain functional ability. Interventions to improve function include both evidence-based nursing approaches and innovative technologies. Crucial to successful intervention is early identification of changing conditions that are precursors of declining health status so that interventions can be offered at the earliest indications of need. Through careful monitoring, deteriorating health conditions can be identified early, such as a shuffling gait (mobility problem), restless sleep (possible medication error or pain), change in activity level (possible heart condition), or a change in one's typical routine (potential cognitive problem).

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A key focus of our work is to investigate the use of sensor technology to monitor and assess potential problems in mobility and cognition of elders in realistic home settings. We are interested in sensing alert conditions such as falls. We are also looking for changes in daily patterns that may indicate problems. TigerPlace provides the realistic elder resident home environment in an operating senior living facility in which we are developing and testing this new sensing and assessment system.

Sensor networks for eldercare have been investigated previously. Glascock and Kutzik proposed the use of motion sensors to infer activities of daily living [3]. The Independent Life Style Assistant (ILSA) developed by Honeywell was also an early system that incorporated passive monitoring [4]. A field study was conducted in 11 elderly homes for 6 months, focusing on monitoring of mobility and medication compliance. Ogawa et al. also document an early study in which two individual participants are monitored for motion activity, sleep time, and appliance use (through wattmeters) continuously for over a year [5]. Beckwith describes a study in an assisted living facility with 9 residents of varying degrees of dementia [6]. Residents and staff each wore a badge for location tracking. The system included motion, door sensors and load cells on the bed. Barger et al. report a monitoring system with 8 passive motion sensors to infer a person's behavioral patterns using probabilistic mixture model analysis [7].

Barnes et al. used motion and door sensors to extract a 24 hour activity profile [8]. An alert could be generated if newly logged data deviated from the stored profile. Majeed and Brown described the "well-being" monitoring of elderly residents with passive sensing from door and motion sensors [9] [10] Logged sensor data were classified via fuzzy rules into one of 6 activities, such as sleeping, preparing or eating food, and receiving visitors. The system was tested with two elderly participants.

Our work differs from many of the above projects in that (1) sensor networks have been installed in the homes of elderly volunteers with a longevity spanning years, (2) we are focusing on passive sensing and reasoning, i.e., the participants do not wear sensors and the system does not use actuators, and (3) we are also collecting data on health and medical events in an effort to correlate sensor data with the health record.

The clinical focus particularly separates this research from other smart home projects [11]. The work builds on existing research by combining sensor technology with individualized clinical nursing assessment to help residents maintain functional independence. Additionally, this project reaches beyond the typical technology used by home health agencies to help collect accurate physiological parameters like weight, blood pressure, pulse, oxygen saturation, blood sugar, etc. [12], [13]. Clinical personnel are using the sensor data coupled with traditional health care assessment to monitor the ongoing health status of residents and help them age in place.

2 The TigerPlace Setting

TigerPlace (www.tigerplace.net) was developed to embody the concept of aging in place. Nurses, physical therapists, occupational therapists, environmental design specialists, and other experts in gerontology were consulted on the design of TigerPlace to maximize the independence of the residents. In addition to a friendly, supportive environmental design, TigerPlace helps residents remain active longer by providing registered nursing care coordination, direct personal care as needed, ongoing nursing assessment (holistic assessment at least every 6 months), social activities, and health promotion activities including exercise classes.

Currently, TigerPlace has 34 residents ranging in age from about 70 to 94 years. There are 4 married couples, and the remaining residents are single. About 90% of the residents have a chronic illness; 60% have multiple chronic illnesses. Common illnesses include arthritis, heart disease, diabetes, and the potential for a stroke. A couple of the residents have early stage Alzheimers. About 15% of the residents use a walker. Several residents use a wheelchair, one wears leg braces, and one is recuperating from a hip replacement and uses a cane. In general, the residents are socially engaged at TigerPlace and are active in the community.

An essential component of TigerPlace is Sinclair Home Care, a Medicare licensed home health agency, providing health care, care coordination, and health promotion activities at TigerPlace. Sinclair Home Care provides private pay services to assist clients with personal care, activities of daily living, medication management, and other long-term care needs. In addition, Medicare services are provided when necessary, for example after a hospitalization to assist with recovery. Sinclair Home Care operates a wellness center at TigerPlace three days per week. Residents may have their vital signs checked, receive assistance with medications, and talk to a nurse regarding health care issues and health promotion activities. Moreover, registered nurses are on call 24 hours a day, 7 days a week.

Sinclair Home Care maintains electronic medical records on the residents of TigerPlace using CareFacts, specialized home health software. Additionally, paper logs of significant health events (hospitalizations, emergency room visits, and falls) are maintained at TigerPlace. A database administrator familiar with the CareFacts software was hired to create de-identified health datasets from the electronic medical records and other health records maintained by Sinclair Home Care.

3 Integrated Sensor Network

The sensor network under development is shown in Figure 1. The network includes three main components: (1) a data logger with bed, motion and stove sensors (developed by collaborators at the U. of Virginia [14]); (2) an event-driven, video sensor network that hides identifying features of the residents; (3) a reasoning component that fuses sensor and video data and analyzes patterns of behavioral activity. The system (without video) has been installed in 15 TigerPlace apartments.

The network currently installed in TigerPlace consists of a set of commercially available X10 motion sensors, as well as a stove temperature sensor and a bed sensor which also use the wireless X10 protocol [16]. Motion sensors are installed to detect presence in a particular room as well as for specific activities. For example, a motion sensor installed on the ceiling above the shower detects showering activity; motion sensors installed discretely in cabinets and the refrigerator detect kitchen activity.

The bed sensor is a pneumatic strip (installed under the bed linens) which measures displacement of the upper body torso to detect presence in the bed, as well as pulse, respiration, and restlessness [15]. A low pulse event is sent if the detected pulse is less than 30 beats per minute; a high pulse event is generated at greater than 100 beats per minute. A normal pulse event is generated for 30-100 beats per minute. Similarly, a low respiration event is sent if the detected breathing rate is less than 6 times per minute, and a high respiration event is sent for rates greater than 30 times per minute. A normal respiration rate is generated for 6-30 times per minute. Four levels of bed restlessness are reported. A level one event is generated for movement up to 3 seconds in duration. A level two event is sent for movement from 3-6 seconds in duration. If movement persists from 6-9 seconds, a level three event is generated, and if continuous movement persists longer than 9 seconds, a level 4 event is sent. Together, these different levels provide a measure of sleep restlessness.

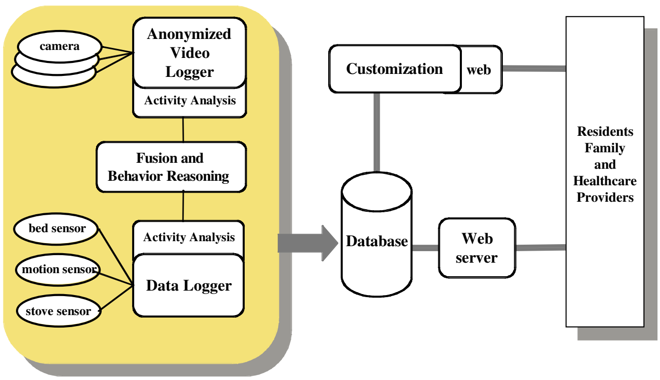

Fig. 1. The integrated sensor network. The data described here are from bed and motion sensors.

The Data Logger collects data from the sensors, date-time stamps the data and logs it into a file that is regularly sent to a secure server which stores the MySQL database. The data is sent as binary streams stripped of identifiers, to ensure HIPAA compliance. The system is non-invasive and exploits simple low-cost sensor technologies [16] coupled with specialized filtering and analysis.

A secure web-based interface was developed to display the sensor data for health care providers, residents, and researchers. The web-interface was refined with input from nursing, health informatics, social work, and residents to ensure it was user friendly and easily interpreted. The interface allows users to select a specific participant and a date range. Sensor data is grouped by category: motion, pulse, breathing, and restlessness. Users can further drill down in the interface to view data from individual sensors. The total number of sensor firings may be aggregated in increments ranging from fifteen minutes to daily and the data can be displayed in a variety of ways including line graphs, histograms, and pie charts.

To detect falls and to track pertinent data on gait, range of motion, and balance (which may indicate a risk of falling), we are also developing a video sensor network. The video network complements the data logger by collecting more detailed information that is not available in the current sensor suite. To preserve the privacy of the residents, several techniques are being investigated. One strategy is to identify a moving person in the image and create a *silhouette*.

4 Case Studies

Using the sensor network web interface, sensor data was retrospectively compared to health events including falls, emergency room (ER) visits, and hospitalizations with a goal of detecting predictive patterns and developing methods for tracking ongoing health status. All participants gave informed consent for the use of their medical records as well as sensor data. An exploratory multiple case-study methodology was used because the complex data analysis focused on linkages traced over time, rather than mere frequencies of incidences [17]. Patterns in the data emerged when the data was aggregated to a daily level instead of smaller time frames. Circadian rhythm aggregated data is particularly helpful and has been used in research observing night time restlessness [18].

4.1 Case Study #1

A 96 year old woman living alone in her apartment had a significant cardiac event on June 3, 2007 and was taken to the ER. She was hospitalized on June 5, 2007. She eventually passed away in the hospital. She had a history of heart problems including a diagnosis of congestive heart failure. While frail, she was leading a relatively normal active life with her congestive heart failure managed quite well prior to the cardiac event. In reviewing her sensor data after the health event occurred, a significant increase in bradycardia (slow pulse rate of 1 to 30 beats per minute) was detected, possibly indicating a potential problem. A decrease in bed restlessness at all levels was also noted during this same time.

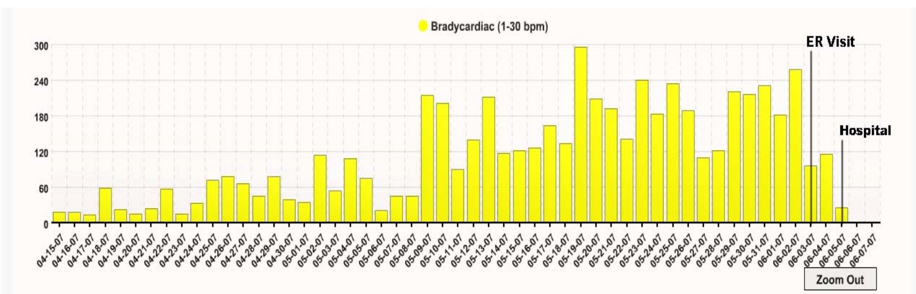

Fig. 2. Screen shot of web-based interface with the addition of marks denoting the ER visit and hospitalization showing sensor data indicating increase in bradycardia (slow pulse rate). The graph represents the total number of bradycardia bed sensor firings aggregated to a daily level for the time frame April 15, 2007 to June 7, 2007.

Unusual signs that would have predicted the impending cardiac event were not detected in traditional physical assessment and observation of the registered nurse care coordinator or other health care providers. Her clinical diagnoses and medication revealed cardiac problems, but could not be used to predict an event. She was receiving assistance daily in the morning to assist with bathing, dressing, and other personal care. Observationally, she seemed to be managing her activities of daily living well and was in relatively good health.

The sensors detected health changes which traditional health care assessment did not. If the sensor data had been detected before the heart attack and the clinical staff alerted, they may have intervened which may have delayed or prevented the cardiac event, thus prolonging the health of the participant.

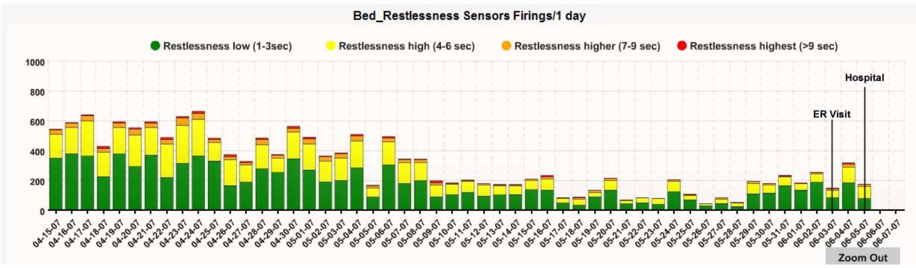

Fig. 3. Screen shot of web-based interface showing bed restlessness sensor firings aggregated to a daily level for the time frame April 15, 2007 to June 7, 2007. All levels of bed restlessness (low, high, higher, and highest) are included.

4.2 Case Study #2

A 79 year old male underwent cardiac rehabilitation, a program of education and exercise following cardiac surgery or other heart problems. He had a heart attack and coronary bypass surgery in December 2005 and underwent cardiac rehabilitation to assist in his recovery.

Following the coronary bypass surgery, he was extremely restlessness while in bed (Fig. 4). This increase in bed restlessness could have been associated with pain while recovering from the surgery, new medications, or other unknown factors such as complications following the surgery. After the rehabilitation program, the bed restlessness returned to normal pre-surgery levels (Fig. 5), which could suggest that the restlessness was related to ongoing issues with his heart that were improved with the exercise and lifestyle changes associated with cardiac rehabilitation.

In this case, the sensor data could have been coupled with traditional health care assessment to provide a clearer picture of his overall health status. The sensor data clearly signified problems, as noted by increased restlessness, immediately following the bypass surgery until the middle of February following the successful completion of the cardiac rehabilitation program.

5 Discussion

The two case studies presented in this paper illustrate the potential of sensor data to augment traditional health assessment by health care providers. In this retrospective analysis, patterns seem obvious that could have been used to prompt health care providers to take a closer look, assess in more detail or depth, and be alert to potential complications or changes in health status. More work is needed to understand the possibilities that sensor data can provide an early "warning" system that a condition needs additional attention. However, in both of these cases such an early "warning" appears to have been possible, as patterns in the sensor data pointed to changes from prior sensor readings.

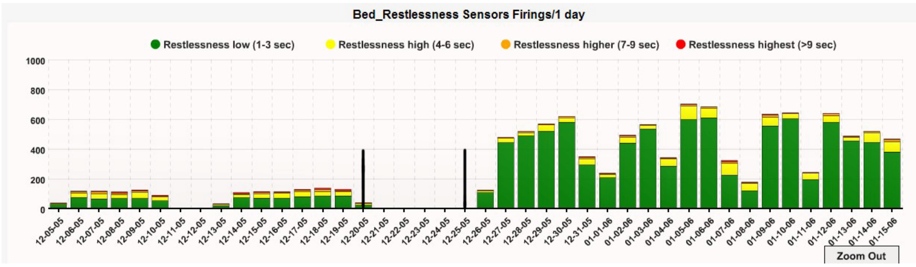

Fig. 4. Increase in restlessness (all levels) following his bypass surgery. The dates of the hospitalization with surgery are marked with solid lines. The graph represents total bed restlessness sensor firings aggregated to a daily level for the time frame December 5 to January 15, 2006.

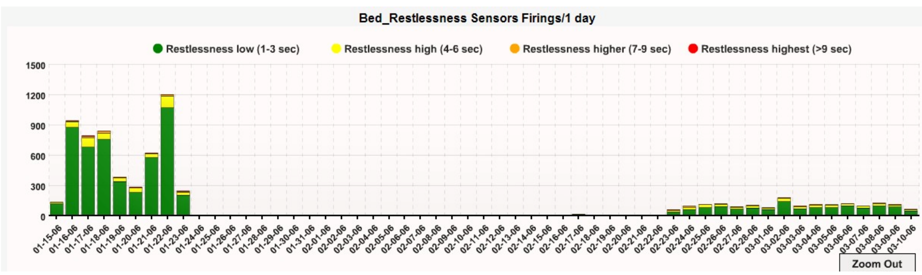

Fig. 5. Return to normal bed restlessness (all levels) following cardiac rehabilitation in January and early February. The graph represents total bed restlessness sensor firings aggregated to a daily level for the time frame January 15 to March 10, 2006. The dates where there are no bed sensor firings are when he did not sleep in his bed; some of these dates he was staying with family while recovering from cardiac procedures.

Using similar retrospective methods, additional case studies have been completed on hospitalizations, falls and other emergent events with the goal of establishing meaningful alerts to notify health care providers of impending problems. Early detection is the key to healthcare interventions which could delay or prevent serious health events and technology provides the means to early detection. With additional case studies, we are optimistic that patterns such as those presented in this paper will be able to be recognized by the sensor network and used as an alert or early "warning" to health care providers. Additional work is underway to establish these health alerts, improve the reliability and accuracy of the sensor network, implement the video sensor network, and refine the web-based interface to make it even more user-friendly and meaningful to health care providers.

Acknowledgements

This research was supported by the U.S. Administration on Aging grant #90AM3013 and the National Science Foundation ITR grant IIS-0428420.

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Observing Outdoor Activity Using Global Positioning System-Enabled Cell Phones

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Abstract. Global positioning system (GPS) technology offers a methodological advance over existing methods of assessing exposure to social and built environments in health studies. The usefulness of GPS-enabled cell phones with open-source software to track users in real-life situations was assessed by carrying phones through three standardized loops in Portland, Oregon. Overall, the cell phones recorded position in 62.8% of tests. Position acquisition varied by the environment in which the cell phone was carried, highest in open areas (83.5%) and lowest under cover (37.5%). The ability of the cell phones to track varied by mode of transportation. Tracking performance was adequate when moving by car (46.6%) or on foot (29.9%), but low on public transportation (3.8%). The GPS-enabled cell phone system showed adequate reliability under typical study conditions to track outdoor activity. Systems built on consumer electronics offer inexpensive and reliable technology for clinical/epidemiological location-based studies.

Keywords: global positioning system (GPS), location-based studies (LBS), cell phones, outdoor monitoring, neighborhood.

1 Background

Rural residents are more likely than urban and suburban residents to have characteristics associated with poor health;[1] in particular, rural older adults have greater functional disability than urban elders.[2]

Social networks are supportive of mental and physical well-being.[3] Neighborhoods function as an important social network for older adults,[4,5] particularly for older adults living in rural communities, who have a greater sense of neighborhood than those living in urban communities.[6] However, a neighborhood's ability to provide social connections necessary for social networks may be influenced by its physical qualities.[3] Neighborhoods qualities can also influence physical activity.[7] While physical activity is important for maintaining health, rural older adults are more sedentary than urban elders and increasingly sedentary with age.[8]

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 177–184, 2008.

Therefore, neighborhood – and the interaction between older adults and their community – may be a key to understanding healthy aging. However, research of neighborhood contexts and health is limited by existing methods of assessing behavior,[9-12] which rely on recall of past behavior and are prone to biases related to memory, cognition, and social desirability,[10,11] or occur in laboratory settings rather than normal context.[12] Additionally, neighborhood is often defined based on arbitrary boundaries rather than the lived experience, Thus existing research ignore the highly individualized and complex relationship between people and place, underestimating the total effect of neighborhood on health.[9,13,14]

Global positioning system (GPS) technology provides a tool to better understand individual exposure to social and physical environments.[9,15,16] But while GPS technology offers a methodological advance over existing methods, off-the-shelf systems are limited by cost, proprietary software, and poor user compliance. Therefore, we propose tapping into GPS-enabled consumer devices, such as cell phones, which may offer researchers falling costs, rapidly improving features, reliability, and in some cases, software open to outside developers. We developed a system using a standard cell phone, the Motorola i760, which uses assisted GPS (A-GPS) and provides a JSR-179 compliant location API. The current price of the i760 is $120 with a $39 monthly plan from Nextel. At study initiation, similar units cost $375. The i760 weighs 133 g and fits comfortably in a pocket. Unlike currently marketed GPS-integrated cell phones, its software is open to outside (non-proprietary) extensions, allowing for this study to customize data collection and cleaning. All of our software was developed in Java.

As part of an on-going research project, we evaluated the reliability and validity of GPS-enabled cell phones to track outdoor activity under typical study conditions.

2 Methods

Six Motorola i760 cell phones were tested. Using open-source software developed for the study (http://www.cs.uoregon.edu/research/wearables/gypsy.php), the phone's GPS coordinates were (a) dynamically obtained using the manufacturer's recommendations on sampling intervals based on current error calculations, and (b) transferred to a secured central server using ssl-enabled http tunneling, when the local buffer reached capacity (every 5 seconds on average). Location was recorded in latitude and longitude using the Motorola proprietary application program interface (API), which uses WG584 datum.

2.1 Static Assessments

The battery life of the cell phones was assessed by measuring the time to run down a fully-charged phone. Phones were tested simultaneously; they were turned on at the same time and were carried together. The time until the onset of the phone's low battery level warning and until the phone turned off due to low battery power were recorded.

Inter-phone reliability and position validity were assessed by comparing cell phone GPS recordings and a known GPS reference point. The phones were simultaneously placed at a geodetic point in Beaverton, Oregon for 25 minutes. For comparison, an off-the-shelf unit (GPSmap76CS, Garmin LTD, Olathe, KS) was also placed at the geodetic point. Recorded positions were mapped using ArcGIS v9 (ESRI, Redlands, CA, USA).

2.2 Free-Living Assessments

The capability of the cell phones to track users in real-life situations was assessed by carrying the phones through three testing scenarios simulating typical paths in the Portland region. To best assess the capabilities of the phone, the scenarios were designed to challenge the cell phone's ability to obtain a position. Testing scenarios consisted of testing points along a standardized path. This design allowed for assessment of the reliability of the cell phones at specified points as well as along a path. An "Urban" loop of ten testing points in downtown Portland was traveled by bus, streetcar, and walking. A "Suburban" loop of nine testing points in an area characterized by suburban development was primarily traveled by car. A "Hill/Forest" loop of ten points in residential, park, and forest settings in a hilly area was traveled by car and walking. The effect of body placement of the phone was assessed by carrying each phone twice through each loop, once on a belt clip and once in a pocket.

All testing loops were completed by a research assistant that carried two phones at one time, one at each body placement. After verifying adequate battery power and placing the phones in the appropriate body position, no effort was made to position the phones to obtain a "better signal" or to verify that the phone was tracking, in order to replicate real life data collection. At each testing point, the research assistant paused for 1-minute or longer, depending on traffic lights and transit schedules.

Position acquisition was measured as the proportion of trips with successful position readings at a specific testing point. The denominator was the total number of trips through a loop, excluding testing scenarios during which phones malfunctioned or the testing point was skipped. A cell phone's success in recording position at a testing point was determined by mapping the coordinates in study software and by viewing the GPS coordinates in Excel (Microsoft, Redmond, WA, USA). A successful position reading was defined as a reading during the pause at the testing point; readings taken before or after the testing point were not included.

Tracking performance was measured as the number of actual position readings as a proportion of expected readings. The number of expected position readings on a transportation path was calculated by dividing the number of seconds on a path by 5.5. Transportation paths were determined using a process similar to establishing testing points; location data were reviewed in Excel and the study software to identify start and end points. Time waiting at testing points along the transportation path was included in the total time on the path. Transportation paths on trips during which phones malfunctioned were excluded from analysis.

Mean position acquisition and tracking performance was calculated in SAS v9.1 (SAS Institute Inc, Cary, NC, USA). Confidence intervals around the mean were calculated in Excel using Wilson's binomial approximation.[17]

3 Results

3.1 Static Assessments

In the battery test, the shortest lived battery was exhausted after 14 hours. Battery testing for one phone was truncated after almost 42 hours, perhaps indicating error. Excluding the outlier, the phones were on for an average of 18 hours and 42 minutes before loosing adequate battery power.

Results of the static inter-phone reliability and validity test are shown in Figure 1. One phone failed to record data during the test. Of the five remaining phones, the distance between the modal recorded location and the true location ranged from 11-15 meters. The modal location recorded by the Garmin unit was 3 meters from the true location.

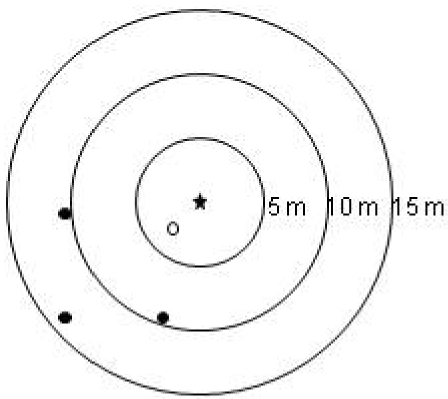

Fig. 1. Static inter-phone reliability and validity assessment using GPS-enabled cell phones indicate that the five GPS-enabled cell phones (*black dots*) were within 11-15 meters and the Garmin unit (*open dot*) was within 3 meters of the true location (*star*). Cell phone location coordinates overlap, resulting in fewer markers than phones.

3.2 Free-Living Assessments

GPS-enabled cell phones were tested in 36 trips with 348 testing points and 156 transportation paths. Software freezes resulted in missing data during three trips. An additional six potential readings were excluded because the testing point was skipped. A total of 33 trips with 312 potential position readings (90%) and 133 transportation paths (85%) were used in this analysis.

Overall, 62.8% of testing point visits resulted in a successful position reading [Table 1]. Position acquisition ranged from 10% to 92% across testing points, with three-quarters of testing points exceeding 50%. Position acquisition was significantly higher in the suburban loop (67.3%), as compared to the hill/forest loop (62.2%) and the urban loop (59.1%), as shown by 95% confidence intervals that do not overlap. Position acquisition was not significantly different when inside a car (60.8%) versus outside (63.4%).

Table 1. Position acquisition by scenario, wait type, and environment

	Number of trips	Position Acquisition Mean (%)	Position Acquisition 95% CI (%)	
Overall	312	62.8	62.1 - 63.3	
By Scenario				
Urban	110	59.1	57.1 - 60.5	
Suburban†	104	67.3	64.9 - 68.5	*
Hill/Forest‡	98	62.2	59.9 - 63.7	
By Wait Type				
On Foot	238	63.4	62.4 - 64.0	
In Car	74	60.8	57.8 - 62.7	
By Environment				
Open Area	85	83.5	79.9 - 84.2	*
Low-Rise	70	70.0	66.4 - 71.6	*
High-Rise/Sunken	85	57.6	55.2 - 59.5	*
Covered	72	37.5	35.6 - 40.7	*

CI, confidence interval; * indicates p<0.05.
† 4 trips excluded due to skipped testing points.
‡ 2 trips excluded due to skipped testing points.

However, position acquisition did depend on the environment surrounding the testing point. The proportion was significantly higher in open areas (83.5%) than in areas with low-rise development (70.0%), below ground or with high-rise development (57.6%), or under cover (37.5%). Qualitative review of the environment surrounding testing points with low and high position acquisition supports these findings [Figure 1].

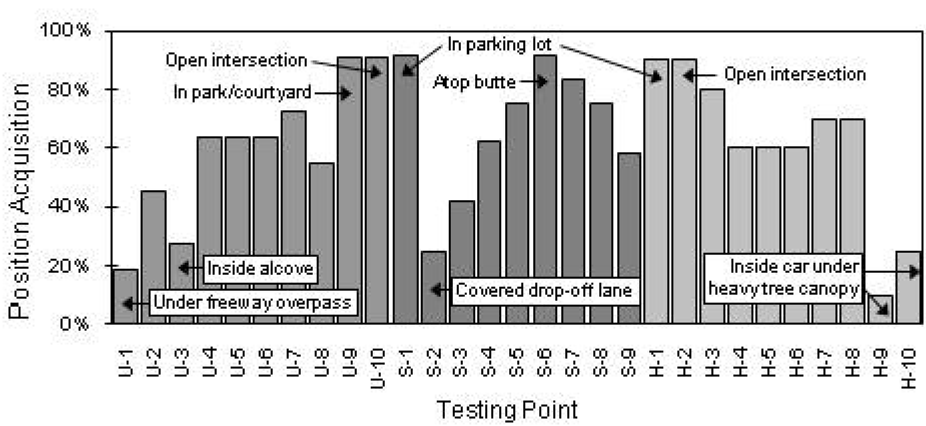

Fig. 2. Position acquisition by testing point. The five points with position acquisition below 40% were all covered, while the six points with proportions above 90% were all in open areas.

Tracking performance varied significantly by mode of transportation [Table 2]: 46.6% in a car, 29.9% on foot, and 3.8% on public transit. Subgroup analyses found no significant differences by city and freeway car travel or by bus and streetcar public transit. Although tracking performance was higher when the phones were carried on the belt clip (37.0%) than in a pocket (32.6%), the difference was not significant.

Table 2. Tracking performance of GPS-enabled cell phone by transportation mode and body placement

	Number of trips	Tracking Proportion		
		Mean (%)	95% CI (%)	
Overall	133	34.8	33.8 - 36.7	
By Transportation Mode				
Pedestrian	44	29.9	27.5 - 35.6	*
Personal Vehicle	56	46.6	43.6 - 50.0	*
Public Transit	33	3.8	3.4 - 13.8	*
By Body Position				
On Belt	69	37.0	35.1 - 40.3	
In Pocket	64	32.6	30.8 - 36.4	

CI, confidence interval; * indicates $p<0.05$.

4 Discussion

This feasibility study demonstrated that a lightweight, GPS-enabled cell phone can measure exposure to neighborhood environments of adults in the Portland region, although data quality varies by context. Assessment of the cell phones' battery life showed that while battery life varied across phones, all phones had adequate power to cover a full day's activities away from the home. In static tests, the GPS-enabled cell phones demonstrated inter-phone reliability and provided valid location data within 15-meters.

The cell phones tested in this study were capable of obtaining position data when used in scenarios similar to real life travel. No significant differences in position acquisition were observed between wait locations. However, the surrounding environment was an important factor in position acquisition. The cell phones could better obtain position in relatively open areas or in suburban areas, which have lower-density development.

Tracking performance of the phones was low. No mode of transportation had an average tracking proportion greater than 50%. While the tracking performance of the cell phone for car and foot travel was generally adequate for reviewing a day's activities and exposures, it would not be appropriate for real-time tracking of a user within a street network. Surprisingly, the phones tracked better when traveling in a car than on foot. This difference may reflect the environments in which the two modes of transportation were used. Cars were predominantly used in more open environments where position acquisition was high, whereas walking was used in dense, sloping, and urban areas where position acquisition was low. In future studies with a larger number of trials, we will further assess interactions between environment and mode of transportation.

Results for the GPS-enabled cell phones are similar or better than other studies testing similar systems, both custom[13] and off-the-shelf,[14,18,19] in real-life settings. A study of children wearing a specially designed unit[13] reported an outdoor position acquisition of 79.1%, although outdoor data was obtained on only two of the eight subjects. Two studies using the Foretrex 201 portable GPS unit (Garmin LTD, Olathe, KS, USA) reported position acquisitions of 59.3% for 32 adults over three days[18] and 30% for 25 adults over 24-hours.[14] Data loss was primarily attributed to low battery life.[14] A wildlife telemetry study[19] reported 20% position acquisition for a Televilt Porsec 120 (TVP Positioning, Lindesberg, Sweden) worn for eight-days by an adult monkey. Similar to our findings, data loss was attributed to the difficulty of obtaining location in heavily forested areas.

In addition to being adequately reliable, this open source, GPS-enabled cell phone system is small/light, discrete, and convenient. The cell phone used in this study weighs less than three of the four units used in prior studies (range: 78g to 2000g).[13,14,18,19] Cell phones are commonly used and thus a person carrying a cell phone for research purposes is not easily identified. Additionally, activities related to a cell phone (e.g., regular charging and remembering to take it when leaving the home) are likely to improve compliance among study participants. Several limitations of this study should be noted. Software freezes resulted in lost data; the problem was diagnosed after testing and corrected. The position acquisition rate was assessed at a specific point, not in a general area. These results therefore may underestimate the usefulness of the technology. For example, a research protocol involving the GPS-enabled cell phones could infer missed location data using nearby position recordings. Tracking performance included time spent waiting at testing points and may be overestimated if the cell phones were better able to record location when still than traveling. Because the exact amount of time spent waiting was not known, subtracting waiting time would likely have introduced a larger amount of bias into the tracking performance analysis. The number of trips through the testing scenarios was limited. Additional trips may yield more precise estimates and reveal significant differences.

In conclusion, GPS-enabled cell phones are a promising new tool to characterize exposure to social and built environments in studies of older adults living in diverse communities. Additional development and testing will be required to use these phones for real-time tracking of older adults within their communities. The second phase of the ongoing research project will use the phones to investigate where older adults travel, comparing trip transportation, purpose, and path. This study seeks to describe participant “neighborhood” based on actual use, rather than standardized boundaries, as well as characterize trips made near home, which could potentially be walked instead of driven. In addition, the role of environment and mode of transportation on data reliability will be further investigated.

Acknowledgements. The project was supported by funding from the Oregon Roybal Center for Translational Research and the National Institutes of Aging (AG024978-03) and Intel. We thank Mark Bosworth and Beth Goralski at Metro for their contribution to the spatial analysis.

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MISS: Medicine Information Support System in the Smart Home Environment

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Abstract. The Smart Home uses different technology to facilitate the lives of the resident and is especially useful for assisting the elderly and persons with special needs. One area where this population would benefit is managing their prescribed medications. This paper presents the Medicine Information Support System (MISS) which integrates the patient's information to assist with the prescriptions management. The system checks for conflicting medicines, health conditions and food items. The data generated is used to feed other subsystems in the Smart Home such as the reminder and medicine inventory. A formal model is introduced for conflicts checking. The three main entities: doctor, pharmacy and Smart Home use this model to detect their particular set of conflicts which ensures that conflicts involving the entire context will eventually be detected. The design uses this model as its basis for conflict checking. The prototyped implementation of the entire system is based on Java.

Keywords: Smart Home, doctor, medicine, pharmacy, formal model, conflict checking, RFID, OSGi.

1 Introduction

The Smart Home is a house that integrates different technologies for facilitating the execution of daily tasks. Sensors and actuators play a major role in assisting in the automation of these tasks. Smart Homes, with modern technology designed especially for the elderly and persons with special needs, have been a research subject in the last few years. One main motivation for this research is that the baby boomer generation is reaching the retirement age and the need for assistance increases as they grow old.

One of the areas in which the elderly and persons with special needs would need assistance from the Smart Home is in their medicine intake management. Keeping up-to-date with the prescriptions can be challenging due to complicated medicine names, several simultaneous medications, similar instructions for medication intake for different medicines, and being aware of expiration dates and detecting conflicts.

We propose MISS: Medicine Information Support System in the Smart Home to address this issue. A step-by-step analysis of the process for getting prescriptions today is presented. This analysis helped identifying important requirements for our

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 185–199, 2008.

system. As a result we come up with a formal model which is used for detecting errors and conflicts among sets. These sets are the medicines, food items and patient's health conditions and the system checks for conflicts among those. This system generates data which can be used by other subsystem in the Smart Home. The reminders system which tells the patient when to take the medicines is one of these subsystems that benefits from MISS. Also MISS data is useful for preparing and updating a personalized calendar and providing individual assistance for each user at the time of taking the medicine.

There have been previous efforts for helping individuals with the management of their prescriptions. Some related work includes the Magic Medicine Cabinet (MMC) which is presented in [1]. In that project the author mentioned that today's smart devices are designed to perform the device tasks plus connecting to the Internet. This converts the appliance to a device similar to a personal computer which also can go online. MMC is equipped with a facial recognition software, RFID smart labels, vital signs monitor and voice synthesis. The MMC assists the residents of the house by giving personalized reminders, detecting when a resident take the wrong medicine, and measure some vital signs. The MMC is a great idea but their product is not designed particularly for the needs of the elderly population. They also do not give details of how it interacts with the patient's pharmacy, doctors and health care providers even though the MMC claims it can. Our paper bridges this gap by describing a system in which the Smart Home interacts with the patient's doctor, pharmacy and health care provider. Such a system will be useful for checking conflicts and errors in the process of dispatching medicines, will facilitate giving reminders, and will increase compliance with medication intake [7].

The Smart Medicine Cabinet [2, 3] and the Smart Box [4, 5, 6] extends the Magic Medicine Cabinet by using passive RFID technology and Bluetooth, to synchronize the state of the MMC using a cellular phone. The cellular phone contains information to be used to give reminders and to know the state of the medicine cabinet and its content. They assumed that the medicine containers have RFID tags and the Smart Medicine Cabinet (SMC) can be automatically updated. When the cell phone is within the SMC range, a synchronization phase takes place keeping user intervention to a minimum. Nevertheless this still requires the user to carry the cell phone to the synchronization area as well as to carry it to the pharmacy. Our system presents a simpler synchronization process from the patient's point of view that will not require any intervention from the patient. Also there will be no need of carrying any device such as a cell phone giving our system another advantage.

Technology available for automatic dispensing of prescribed pills can be found in [10, 11]. All these products have some common features. In these machines either the resident of the Smart Home or a caregiver has to load the automatic dispenser with the medications, enter the times that the medicine should be taken, remove the medicines after the system reminds the patient for taking them and repeat these actions for other prescriptions. The disadvantage is that these machines require a lot of manual action.

All these products has some outstanding features that facilitate the task of taking medicines [10, 11], ensuring that the right medicine is taken at the proper time [4, 6] and giving reminders to the patient [8, 9]. Also these products facilitate to some extent the detection of errors during the process such as when the medicines are not taken. But these products by themselves do not address the need of managing medicine information as they still require a lot of manual input from the patient. In [13] a system which uses this technology for helping patients with dementia is presented. Our system is similar in which it uses available technology to help patients with their prescription intake. Our system is different as it involves the doctor, pharmacy and health care providers at early stages. Also we provide a formal model of the system to ensure it is safe, secure and correctly detects the conflicts. Also MISS presents a system in which the patient does not need to enter any data manually and can be integrated with existing reminder systems such as outlined in [13]. The following sections will describe more details of our system MISS. The rest of the paper is organized as follows: Section 2 lists the system requirements. Section 3 describes MISS details and design. Section 4 introduces a formal model of the system. Section 5 explains the conflicts checking at each subsystem. Section 6 shows an instantiation of the model. Section 7 presents the prototyped implementation. Section 8 concludes the paper and presents future work.

2 Current Technology and System Requirements

Describing the process of a person who goes to the doctor and receives a prescription will help to identify important system requirements. This process can be broken down into the following steps:

1. The person visits the doctor.
2. The doctor prescribed some medicines.
3. The patient goes to the pharmacy and gets the prescribed medicines.
4. The patient goes home and intakes the medicines.

Medicines intake involve the following steps:

4.1 Wait for the next dosage time
4.2 Locate the medicine container
4.3 Open the container
4.4 Extract the appropriate amount of medicine
4.5 Intake the medicine
4.6 Close the prescription container
4.7 Return the container to the medicine cabinet

Several of these steps have been automated with existing products. For step 4.1 and 4.2 a Smart Box or Cabinet can help with the reminders and location of the medicines [1, 2, 4, 6]. Using automatic pill dispensers [10, 11] can help in opening the medicines and extracting the right amount as indicated in steps 4.3 and 4.4. These are some examples on how current technology can be used for the purpose of medicine intake but there is still room for improvement. One of the steps which can be further improved is 4.1 where the patient "waits" for the next dosage time. The elderly and persons with special needs might forget when the next dosage is [13]. A system which takes care of reminding them the time of the next dosage will help to increase compliance with medicine intake [7]. Another problem facing this population is to locate the medicine as required in step 4.2. It is possible that they do not remember where the medicine containers were placed last time. Therefore the patient will benefit from a system that will help locating the medicine containers. The automation of a reminder system will require input of the prescription's specific information to be able to give the proper reminder at appropriate time. To enable the location of medicines, a unique identifier for the prescription containers is needed. This will facilitate tracking the object within the Smart Home and distinguishing it from similar products. An efficient mechanism to detect and locate the medicine container is required.

Entering the medicine information manually by the resident or a health care provider for these systems is not feasible. Human errors and typos can occur. Therefore the details about the prescription such as the name, dosage, conflicting medicines, conflicting food, patient conditions and other warnings should be entered by an expert and automatically transferred into the Smart Home system. This way intervention from the resident is minimal so this feature is very important. All this automation will require a reliable system which will accurately compute the existence of conflicts among the prescribed medicines, the food items available at the Smart Home, and the patient health conditions. This data must be accurate as it is expected to be used as input for other subsystems in the Smart Home. The design and the prototyped implementation of the model show how these tasks can be accomplished by our system requiring minimum intervention from the patient. The next section shows the MISS system and design.

3 MISS System and Design

This section has a high level description of the MISS system, it subsystems and their interactions with each other for managing the medicines and detecting conflicts. At a very high level the system should do the following: The patient visits the doctor and gets a prescription. The prescription details are inputted into the system at the doctor's office. The system will check for conflicting medicines and heath conditions based on the patient's record that the doctor has. The patient will indicate from which pharmacy the prescription will be picked up. The doctor then will make the prescription's data available to that particular pharmacy. The pharmacy prepares the prescription based on the doctor's prescription. The pharmacy will double check for conflicting medicines and health conditions based on the patient's record of the pharmacy. The patient picks up the medicines. The patient goes to the Smart Home and in a very convenient way, by scanning the RFID-enabled prescription containers into a RFID-reader, will indicate to the Smart Home system the presence of the new medicine. The Smart Home will update its medicine inventory database accordingly and makes a final check for conflicts among medicines, health conditions and food. MISS consists of three main subsystems: The Doctor Subsystem, the Pharmacy Subsystem and the Smart Home Subsystem. These subsystems are operated by four main actors which are: the doctor, the pharmacy, the patient and the Smart Home. A trusted third party medicine's database that defines the conflicts is also used. A diagram of the system is shown in Figure 1. The next subsections describe each subsystem design more detailed.

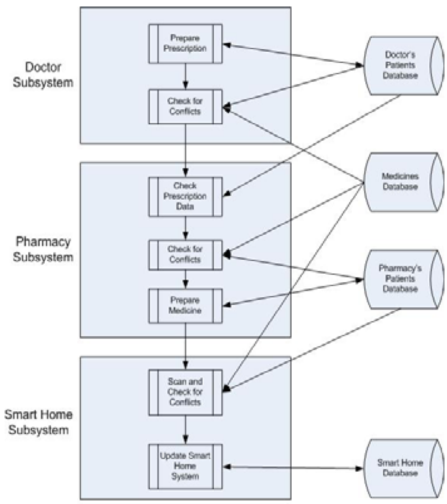

Fig. 1. Medical Information System Diagram

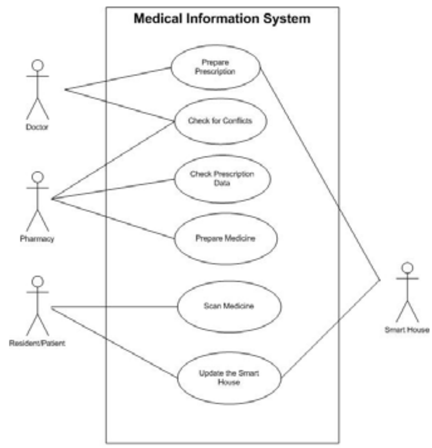

Fig. 2. Use Cases and Actors

3.1 Doctor's Subsystem

The doctor subsystem is where the process starts. During the visit to the doctor, he checks the patient and prescribes some medicine. During the consultation the prescription details such as the name of the medicine, dosage, etc. are inputted into the system. Our system checks for conflicts and also facilitates the communication between the doctor's office and the patient's preferred pharmacy. For doing this the options are to have the doctor's office directly communicate with the patient's preferred pharmacy and send the prescription data or making the prescription data available for a pharmacy that the patient will choose later.

Consider the first case when the patient chooses a preferred pharmacy to pick up the medicines. The person interacting with the system at the doctor's office will use a unique ID such as an assigned patient number, to access the patient's information. This information is stored at a local patient's database, available only to the doctor. The information extracted from the database contains data such as previous prescriptions and health conditions. To ensure that the prescription would not have any adverse side effect on the patient the information extracted from the database will be checked against the data of the new prescription. After carefully checking for conflicts with medicines and health conditions, if no conflict is found the prescription data will be sent to the patient's preferred pharmacy through a secure channel. The doctor's office will also issue prescription document customized for that particular patient and prescription. This prescription will be in the form of printed-RFID tag which will be used later by the pharmacy module.

In the second case in which the patient will decide later from which pharmacy the prescription will be picked up, the process is similar. At the doctor's office the prescription information will be entered into the system, the patient's data will be accessed and check for conflicting medicines and health conditions as in the previous case. But here the doctor's office will not be sending the data to any pharmacy.

Instead a printed-RFID prescription will be issued. This will allow the pharmacy's system to download the prescription data from the doctor's office later on. The main difference among the two approaches is when the data arrives to the pharmacy. In the first case it arrives immediately in the second case when the patient gets into the pharmacy. Now let us consider how the pharmacy subsystem uses this data.

3.2 The Pharmacy Subsystem

Based on the doctor's subsystem operation we assume the following two starting scenarios for the pharmacy subsystem: There is a chosen pharmacy which receives the prescription's data from the doctor's office or the patient will choose a pharmacy later and bring the printed-RFID prescription.

Consider the first scenario in which the patient chose a preferred pharmacy at the doctor's office. The pharmacy will receive the prescription's data with the necessary details when the patient is still at the doctor's office. The pharmacist can start preparing the prescription immediately using this information. The pharmacy will issue the prescription in special containers. These containers will look like regular ones with the difference that they will be equipped with RFID tags. These RFID tags will allow the system to uniquely identify the particular medicine with all its related data. This tag-ID and the related information will be stored in a database that will be used later by the Smart Home module.

Before assigning the RFID tags for the container, the pharmacy system should have available a history of the patient and previous prescriptions dispatched from that pharmacy. The system will check that the particular RFID tag has not been assigned maintaining uniqueness. After assigning unique IDs to each prescription, the system is ready to prepare the data that will be used for updating the Smart Home subsystem. This data consists of two important pieces: the patient independent and the patient dependent information. The patient independent information contains the description of the medicine, possible side effects, different conflicts and recommendations. The patient dependent information is the historical data that the pharmacy has about the patient. This information will be checked in a similar way as it was checked in the doctor's module. The system will be looking for possible conflicts with other medications, and health conditions to make sure it is safe to take that particular medicine. This double check is necessary as the doctor might prescribe a medicine which creates a conflict with a medicine previously picked up at that pharmacy.

At this point the pharmacy is ready to receive the patient. When the patient arrives he shows the printed-RFID prescription the same way they are used to do it now. The difference is that the prescription ready or in process as the patient chose the preferred pharmacy when still at the doctor's office. The printed-RFID prescription is scanned in a RFID reader. At this point the system will compare the data in the RFID tag with the data received from the doctor's subsystem. If no incongruence is found, the medicine is dispatched. Otherwise, the pharmacist is alerted and contacting the doctor's office is recommended. One advantage of our system is that it reduces the waiting time at the pharmacy as pharmacists can start preparing the prescription when the patient is still at the doctor's office. This is an excellent feature especially for the elderly population that might need their medicines as soon as possible or want to avoid long waits or several trips to the pharmacy. Another benefit of our system is the double layer of security checking for conflicting medications and health conditions.

In case that the patient did not choose a preferred pharmacy the waiting time will increase but the process will be almost identical to the one described previously. Instead of having the prescription ready or in process, the patient starts the process of getting the prescriptions when arriving into the pharmacy. At the pharmacy counter the pharmacist will receive the printed-RFID prescription and at that moment the pharmacy system will download the prescription data from the doctor's office and perform all the safety checks for conflicting medicines and health conditions described in the previous paragraphs. At this point whether the patient pre-selected the pharmacy or not, the medicines should be ready and the patient can go home. The process for updating the system in the Smart Home will be very simple from the patient's point of view as the underlying system will take care of all the details.

3.3 The Smart Home Subsystem

This is the moment in which the patient finally arrives to the Smart Home and updates the subsystem with the new prescription's data. Either the patient or a caregiver will be in charge of updating the Smart Home system by scanning each prescription container with an RFID reader. After scanning the prescriptions the medicines can be placed in Smart Medicine Cabinet [2, 4] or loaded into an automatic medicine dispenser [10, 11] or a combination of both technologies for storing the medicines.

At this point the Smart Home system will read the RFID-tags of the prescription container. These tags will contain information indicating from which pharmacy the patient picked up the medicines. The Smart Home will have a secure communication link to the pharmacy. A query will be issued to the pharmacy to retrieve the prescription details and download this data to the Smart Home subsystem, similar to the process of downloading the data from the doctor to the pharmacy. A final safety check for conflicting medicines, health conditions and food items will take place. This check is necessary as the patient might be picking up the medicines from different pharmacies, prescribed by different doctor. The check for conflicting food will be performed at the Smart Home level as it is the subsystem with the database of available food items.

If a conflict is detected then a caregiver will be informed. If no conflict is detected then with all this information, the Smart Home System will update its medicine inventory and provide data to other subsystems such as the reminders and personalized calendar. All these tasks that MISS perform will definitely help the elderly and persons with special needs that have a hard time checking all these safety issues by themselves.

The more important use cases and actors for the MISS system are shown in *Figure 2*. The system will have four main actors: the doctor, the pharmacy, the patient and the Smart Home. From the figure we can see that the doctor actor is in charge of starting the system by preparing the prescription and make it available to the pharmacy. The doctor actor will also be the first one to check for conflicting medications and health conditions. The pharmacy module then will use the information provided by the doctor's office to prepare the appropriate prescription. It will also check for conflicts and will make sure to validate that the data received from the doctor's office is correct. The patient actor will scan the RFID enabled prescription containers to feed the system with the information necessary to obtain the prescription details from the pharmacy's database. The Smart Home actor will then download the prescription's data from the pharmacy and will use it to update it medicine inventory and support the reminder, calendar, notification and location and tracking subsystems. To ensure the accuracy and correctness of the conflict detection a formal model is proposed in the next section.

4 Proposed Model

The medicine management system should be accurate, reliable and provide safety by detecting and informing conflicts. A conflict occurs when a medicine should not be taken together with another medicine, if the patient has certain health condition that the medicine could aggravate or the medicine interacts with certain food items. We are assuming that a trusted third party defines the conflicts and these definitions are publicly available for the model and the system to use them. To check that these kind of conflict do not occur we present the following model whose main components are the set of medicines *M*, the set of food items *F* and the set of medical conditions *C*. The set of food items *F* needs to be considered as some food should be avoided when taking certain medicine. The set of medical conditions *C* needs to be considered as some medicines cannot be taken if the patient has certain conditions.

Now we define several functions that will act over the set of medicines and return useful information. The first function is *conflicting_medicines: M→P(M)*, where *P(M)* is the powerset of the set *M,* which determines the set of conflicting medicines. The next function is *conflicting_food: M→P(F)* where *P(F)* is the powerset of the set *F,* which will return the set of conflicting food items. The other function is *conflicting_conditions: M→P(C),* where *P(C)* is the powerset of the set *C,* which will return the set of conflicting health conditions. Given these sets and function we define the Medicine System Model as follows:

Definition
A Medicine System Model *S* consists of the following sets:

- M, the set of medicines
- C, the set of medical conditions
- F, the set of food items
- D, the doctors, hospitals or clinics the patient visits
- P, the set of pharmacies at which the patient gets prescriptions
- H, the patient's Smart Home

With the following functions:

- conflicting_medicines: M→P(M)
- conflicting_conditions: M→ P(C)
- conflicting_food: M→ P(F)

We want this information to be useful for a particular patient *p*. Each patient will be represented by a tuple.

p = *(id, Mp, Cp, Fp, CMp, CFp, CCp)*. The *id* entry will uniquely identify the patient. Let $Mp \subseteq M$, represents the subset of medicines prescribed to patient p. Let $Cp \subseteq C$ represent the health conditions that patient p has been diagnosed. Let $Fp \subseteq F$ represent the food items that patient p has available. Let *CMp* represent the subset of medicines that are currently in conflict with the medicines prescribed to patient p and therefore should not be prescribed to that patient. *CMp* can be computed as $\bigcup_{m \in Mp} conflicting\_medicines(m)$. *Let CCp* represents the set of medical conditions that the patient should not have in order to take the medicine safely. *CCp* can be computed as $\bigcup_{m \in Mp} conflicting\_conditions(m)$. Let *CFp* represents the set of food items that the patient should avoid while taking the medicines prescribed to him. *CFp* can be computed as $\bigcup_{m \in Mp} conflicting\_food(m)$. This will help to detect when a patient is diagnosed with a health condition and is taking a medicine which is in conflict, or when a medicine is prescribed which is in conflict with an existing health condition. This way the doctor or caregiver can make better decisions.

Now we describe how to construct these sets that complete the patient information. Given a new prescribed medicine *m*, to a patient p, the medicine has some data related to it like the unique drug id, active ingredients, milligrams, and so on. The medicine data can be obtained from the Food and Drug Administration (FDA) [14], or from the Physician's Desk Reference (PDR) [15]. These entities are trusted third parties who define the conflicts among medicines, food and health conditions. These definitions of conflicts will be used in our model and system. Using the data of medicine *m,* we compute $CM = conflicting\_medicines(m)$, which returns the set of conflicting medicines with medicine *m*. We check if there is a conflict by examining if $CM \cap Mp = \emptyset$ and $m \cap CMp = \emptyset$. If both conditions are true then we take $CMp = CMp \cup CM$, to update the set of conflicting medicines for patient *p*. We do a similar processing for the conflicting conditions. We compute the set $CC = conflicting\_conditions(m)$ which returns the set of conflicting conditions with that particular medicine. We then check for conflicts by taking $CC \cap Cp = \emptyset$. If condition is true, we update this information for the patient by computing $CCp = CCp \cup CC$. Similarly we compute the set $CF = conflicting\_food(m)$ which will return the set of conflicting food items for that particular medicine. We then check for conflicting food items by computing $CF \cap Fp = \emptyset$. If this set is empty then no conflict is found and an updated version of the conflicting food items is computed $CFp = CFp \cup CF$. The next section will show how to check for conflicts at each component of the system.

5 MISS Conflict Checking

MISS is composed of three subsystems: The Doctor Subsystem, the Pharmacy Subsystem and the Smart Home Subsystem. MISS will also access a global medicines database from a trusted third party. Each of these subsystems is responsible for checking for conflicts but it is expected that each one captures a more specific set of conflicts than the others. The algorithm for checking conflicts is very similar. Therefore we define the following two routines as follows:

Definition: Get Data (GD)

Input: Prescription $r = (p, m)$

//Get the data of p querying the local database

Query $Mp, Cp, Fp, CMp, CCp, CFp$

//Compute data of m from the global medicines database

Compute CM, CF, CC

Definition: Conflict Checking (CC)

```
Input: Prescription r = (p, m)
Call Get Data (r)
If (CM ∩ Mp = ∅ and m ∩ CMp = ∅)
  If (CC ∩ Cp = ∅)
    If (CF ∩ Fp = ∅)
      //No Conflict found
      CMp = CMp ∪ CM
      CCp = CCp ∪ CC
      CFp = CFp ∪ CF
    Else
      Medicine m creates food conflict
  Else
    Medicine m creates a health condition conflict
Else
  Medicine m creates a medicines conflict
```

5.1 Conflicts at the Doctor Subsystem

In this model it is assumed that the process starts when the patient visits the doctor and is prescribed with some medicine. Therefore at the Doctor Subsystem *(DS)* the model is fed with a new prescription $r = (p, m)$. This prescription r contains the id of the patient p and the id of the prescribed medicine m. The DS will have a local database with information stored about the patient p such as previously prescribed medicines, and health conditions. The DS is assumed not to store any information about food, so this set will be empty. This means that in the DS checking for conflicting health conditions and conflicting medicines will be enforced. This check will be performed by invoking the previously defined function CC with input r. If no conflict is found then the prescription r is sent to the Pharmacy Subsystem for further checking.

5.2 Conflicts at the Pharmacy Subsystem

At the Pharmacy Subsystem *(PS)* it is assumed that the prescription r has been checked at the *DS* and no conflict has been found. The *PS* therefore will receive the prescription r from the doctor. It will then use this information to further check for conflicts. It is expected that the *PS* will have a local database with the patient's record of previous prescriptions and over-the-counter medicines bought at that pharmacy. This data may be different to the one at the *DS*. It is possible that the patient is visiting different doctors and a different prescription from different doctors might be the source of conflict. The patient also might buy over-the-counter medicines which could be the ones that create the conflict, so all of them must be checked. It is assumed that the pharmacy does not store information about food, so this set would be empty. Therefore the *PS* must check again for conflicting conditions and conflicting medicines but using the pharmacy's local data. This is performed by calling the previously defined function *CC* with input *r* using the pharmacy's dataset. If no conflicts are detected the data is clear to be sent to the Smart Home Subsystem.

5.3 Conflicts at the Smart Home Subsystem

The Smart Home Subsystem (*SS*) will receive the data from the *PS* in the form of a prescription *r*. The *SS* is expected to check for any remaining possible conflict among medicines such as those picked up at different pharmacies. We are expecting the *SS* to have a local database with an inventory of the medicines and the food items available. This will allow checking if there is any remaining medicines conflict. The patient might be visiting different pharmacies and different doctors. The medicines prescribed from different doctors might create a conflict at this should be detected at the pharmacy. But if the patient is also visiting different pharmacies, these conflicts can go undetected. These multiple paths of conflicts are the ones that the *SS* will be responsible of detecting. Also again the patient might buy over-the-counter medicine at a gas station or grocery store for example. These can create undetected conflicts as these stores are not part of our system. But when the patient arrives at the Smart Home, the *SS* have the capability of detecting these conflicts with over-the-counter medicines as well. The *SS* also detects any food items in conflict with the new prescription or with over-the-counter medicines. All these checks are performed by calling the function *CC* with input *r* using the *SS* local dataset which includes the medicines inventory of previous prescriptions and over-the-counter medicines, and the set of food items available.

6 Instantiation of the Model and System Design

Now that we have defined the main subsystems we want to ensure that everything works correctly and the system actually detect conflicts. For this instance imagine the following scenario. A patient visits the doctor and the doctor prescribes three medicines. The doctor records indicate a previously prescribed medicine and diagnosed health condition. One of the three newly prescribed medications will create a conflict and this will be detected. Later the patient goes to the pharmacy, where he previously picked up a prescription from another doctor. The system should detect a conflict among the medicines prescribed by these two different doctors. Now the patient arrives home and only one of the three prescriptions so far has not find any conflict. But at the smart home the patient has some food item which should be avoided with that medicine and this is detected by the system. Based on the previous scenario we will present now an abstract instance of the model followed by an instance that uses real data of drug interactions pulled from the PDR Drug Interaction Tool [15].

Let's consider an abstract instance of the model. In *Table 1* we have the patient's data stored at the doctor's module in the row DS, the patient's data stored at the pharmacy's module in the row PS and the patient's data stored at the smart home module in the row SS. *Mp, CMp Cp, Fp* are as defined in Section 5. The medicines *MA, MB* and *MC* are prescribed by the doctor with the data as shown in *Table 2.* CM, CF, CC are as defined in section 5. In this instance we have that for prescribed medicine *MA*, the *DS* will detect a conflict with conditions *C1*, but medicines *MB* and *MC* will find no conflicts based on the doctor's data about the patient. When prescription data arrives to the pharmacy, the *PS* will detect a medicines conflict among prescribed medicine *MB* and previously prescribed medicine *M2*. No conflict is found with medicine *MC* up to this point. When the *SS* checks, it finds a food-drug conflict with prescribed medicine *MC* and food item *F3*. Therefore the patient or caregiver can be informed of this. This is an example on how the lack of information of the entire context can lead to a conflicting prescription, but with this system it will eventually be detected. The abstract model shows that this can be applied to any set of medicines. Also shows an example of the different paths that can create a conflict. In general a patient is seeing different doctors who prescribe different medicines. Prescriptions from one doctor might create a conflict with prescriptions from another doctor and the pharmacy module would detect that. But if the patient is also visiting different pharmacies these conflicts may go undetected. Also buying over-the-counter medicines at places different than the pharmacy can create the conflict. But at the Smart Home subsystem these conflicts would be detected as it works as a sink node. We want to ensure safety in this system which is one of the main motivations to perform these conflict checks repeatedly from the very beginning of the process.

Consider now the case with real drug interaction data set pulled from the PDR Online Drug Interaction Tool. In Table 3 we have the data stored at the doctor's module in the row DS, the data stored at the pharmacy's module in the row PS and the data stored at the smart home module in the row SS. Table 4 shows the medicines prescribed by the doctor in this case Zoloft, Percocet and Allegra. The data about the conflicts is also presented in each column. At the doctor's module the patient's data indicates he was previously prescribed Ambien and has a condition of hallucinations. Therefore a conflict is detected with the prescribed medicine Zoloft which is not recommended if a patient has hallucination and also conflicts with Ambien. The rest of the prescription Percocet and Allegra find no conflict with Ambien. At the pharmacy the patient previously had a prescription of Xanax from a different doctor. Therefore a conflict with Percocet is detected as these two medicines should not be taken together. The medicine Allegra has found no conflict yet. Now at the Smart Home module we have the medicines inventory and the food inventory. A conflict is found between Allegra and Orange Juice as they should not be taken together. In the next subsections the prototyped implementation of this model are described.

Table 1. Patient's data at each subsystem

	Mp	**CMp**	**Cp**	**Fp**
DS	M1	M11	***C1***	F1
PS	**M2**	***MB***	C2	F2
SS	M1, M2, M3	M11, MB, M33	C1, C2, C3	F1, F2, ***F3***

Table 2. Prescriptions at DS

M	**CM**	**CC**	**CF**
MA	M0	***C1***	F11
MB	***M2***	C22	F22
MC	M32	C33	***F3***

Table 3. Patient's medicines at each subsystem

	Mp	**CMp**	**CCp**	**Fp**
DS	***Ambien***	Zoloft	***Hallucinations***	*
PS	Xanax	***Percocet***	*	*
SS	Ambien, Xanax	Ambien, Percocet	*	***Orange Juice***

Table 4. Example of a prescription at DS

M	**CM**	**CC**	**CF**
Zoloft	***Ambien***	***Hallucinations***	*
Percocet	***Xanax***	*	*
Allegra	*	*	***Orange Juice***

7 Prototype Implementation

The prototype implementation of several use cases in our Smart Home Lab shows the feasibility of this system. The Doctor, Pharmacy and Smart Home Subsystems have been implemented as follows. One node has a customized application for inputting the prescription details and stores these in a database acting as the doctor's module. This node sends the data to another node which acts as a server with the patient dependent and patient independent information corresponding to the pharmacy. It assigns an RFID tag to the prescription received from the doctor's module. Then we have another node acting as the client, querying the pharmacy's computer using an RFID tag as the key. We used a Phidget RFID reader [16] and assigned different RFIDs to several containers and tested the reading of tags. After reading the tag the client computer queries the pharmacy database and downloads the specific information that matches the RFID-tag as the primary key. The information includes details about the prescription. This data obeys a format that the Smart Home can store it in its database and use it to update other subsystems such as the reminder, notification and medicine inventory. When a conflict is detected the corresponding message is displayed. The Smart Home subsystem was developed as a bundle that runs is OSGi, a framework particularly suitable for Smart Home applications [17]. The flow of data was correctly transferred from the Doctor's node all the way to the Smart Home and the experimental conflicts were correctly detected.

8 Conclusions and Future Work

The management of medicines and prescriptions by the elderly and people with special needs might be a challenging task for this population. A system that reduces manual intervention and a model for checking and detecting conflicts is presented. This system starts with a visit to a doctor which enters the prescription information into the system and check for conflicting medicines and health conditions. This data is made available to the pharmacy, through RFID-enabled prescriptions. The pharmacy performs a double check for conflicting medicines and health conditions and prescriptions are dispatched in special RFID-enabled containers. The patient scans the special containers in the Smart Home which updates the system with the data it downloads from the pharmacy. The Smart Home checks for conflicting medicines, health conditions and food items and if no conflict is found updates the calendar, reminders, inventory and other subsystems. MISS, the system described in our paper correctly detects conflicts using a formal model and will facilitate the task of giving reminder and increasing medicine in-take compliance. Integrating this system with the whole medicine dataset provided by the official governmental and medical entities such as the FDA and PDR is on-going.

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Challenges of Designing Privacy Enhanced Context-Aware Middleware for Assisted Healthcare

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Abstract. After more than fifty years of designing computers that require users to adapt to them, we now enter the epoch of *human-centric computing*, where systems are designed to adapt to users. A primary concern in ubiquitous computing research is to understand the potential relationship between computation and embedded context. Developers currently face challenges in interpreting context and incorporate little support in designing frameworks that help end-users manage their privacy in an intuitive way. In this paper, we investigate context in assisted healthcare, and provide a more comprehensive definition of context. Based on this, we present the major challenges faced by developers in creating privacy enhanced context aware ubiquitous middleware.

Keywords: Ubiquitous Healthcare, Context Awareness, User Privacy.

1 Introduction

Ubiquitous computing represents the concept of seamless "everywhere" computing and aims at making computing and communication essentially transparent to the users. It usually implies embedding the technology unobtrusively within all manner of everyday computers/appliances which can potentially transmit and receive information from the others. A primary concern in ubiquitous computing research is to understand the potential relationship between computation and the context in which it is embedded, resulting in the need for information fusion applications. However, these applications suffer from a high degree of complexity owing to the heterogeneous data acquired from the plethora of deployed sensors with varying degrees of uncertainty. It is dangerously complacent to assume that social and organizational controls over accessibility of personal information are sufficient, or that intrusions into privacy will ultimately become acceptable when traded against potential benefits. Such a position could leave individual users with a heavy burden of responsibility to ensure that they do not, even inadvertently, intrude on others. It also leaves them with limited control over their own privacy. This problem is emphasized in assisted healthcare, where medical records and history are sensitive information.

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 200–207, 2008.

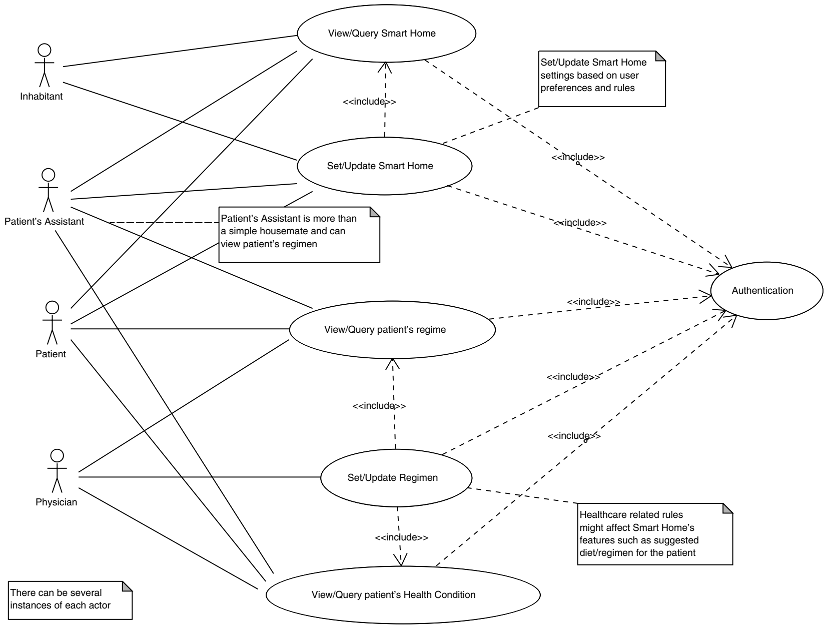

Fig. 1. Use case Diagram of a Smart Home for Assisted Healthcare

Figure 1 describes the use case diagram of a smart home environment for assisted healthcare. A smart home consists of multiple inhabitants with heterogeneous sensors and health monitors deployed in a home to capture the various contexts of the inhabitants and monitor their health. One or more inhabitants could be patients and an external actor could be included for assisting the patients. A physician would be able to monitor, remotely, the physiological state of the patient and make changes to the regimen/diet of the patient. The smart home intimates the necessary persons about the change in the regimen/diet. Owing to the myriad sensors deployed in a smart home environment, a proper understanding of context is crucial for efficient smart home monitoring.

2 Understanding Context

The perception of "context" has been adapted to the computing domain from its original application to linguistics. Winograd [1] points that this notion is reflected in the structure of the word. Composed of "con" (with) and "text", the meaning of context implies "inferring from the adjacent text". If we translate this to the computing domain, context is the representation of the machine or the system along with the larger world in which the user is present and the presence or absence of entities in the world. This implies that context refers to the conditions in which something exists or occurs (situation). Dey [2] defines context as *"any information relevant to an interaction that can be used to* *characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves"*. While we concur with this rationale for Dey's definition, we observe some significant shortcomings when the definition is applied to ubiquitous healthcare. Context is more than just data or information - it is knowledge. We define the three terms in the following way: Data is just an informal piece of information without explicit structure or format. Information is interpretation of informal pieces of data which are associated with a particular context. When contextual information is interpreted and understood, we then have knowledge.

According to Dey's definition, context only exists if there is an interaction between the user and the application. This limits the definition of context to an occurrence of an event and does not encompass the other contexts, especially in assisted healthcare. If the user is sleeping, and does not interact with any application, we would lose precious information of the context (sleeping). In a pressure sensitive floor, when no one walks or sits, we still have information about the absence of a user, and that would also correspond to context. Context therefore, should not be just an interaction between the user and application, but any information obtained from the user actions (or inactions) with respect to an application.

Another problem with the definition is the characterization of the situation of an entity. It is not necessary that an entity should be in a situation to define context. Situation implies " relation to its surroundings", which connotes that context is focused on location. In assisted healthcare, location is just one of the characteristics of context and we have to develop an extensible model of context, where the specific aspects of knowledge about the user and the environment are aggregated and context-aware policies are applied.

We define Context of an entity as "*a collection of measured and inferred information of a state or environment in which the entity has had an interaction, either passive or active, to enable perception of the current state of the entity from the obtained knowledge, which influences inference of the future states*". Our definition stresses upon information collected from various sensors, and inherent information obtained from reasoning about the state or environment, which form knowledge. We use this knowledge to perceive the state of the entity and consider decision making as a function of the prior context about an entity, allowing us to predict future states of the entity.

For effective perception, context has to be classified into two general categories – *user environment*, which consists of the information on the user, information on the user's social environment, and information on the user's activities, and *physical environment*, which encompasses location information, infrastructure information and information of the physical conditions. Intuitively, a systematic method of classifying the user's context information would involve exploration of the context in physical and temporal dimensions, and an attempt to classify the context in terms of user interactions and social nuances. A user-centered approach is preferred in assisted healthcare, where context is grouped into four categories: (1) the physical environment around the user; (2) the user's activity (3) the history of prior activities (4) the user's physiological state. The perspective of these categories and their interpretations of various context parameters is depicted in Table 1. Since context-aware computing is for human-computer interactions in healthcare, using the user-centered scheme to classify context is a natural evolution in context handling.

Table 1. Perspectives of context

Perspective	**Location (absolute)**	**Proximity (relative)**	**Time**	**People**	**Connectivity**
User	Community, address, street, city	Orientation, room, car	Work, party, meeting	Associates, assistants, friends, co-inhabitants	Computer, PDA, Cell Phone
Physical environment	Geographical information, weather	Vicinity, temperature, humidity, vibration	Time, day, date, season	One-to-one, one-to-many	Computing environment, n/w capabilities, communication bandwidth
Activity	Geographical information	Vicinity	Occasion	Individual, group, non-face-to-face	Active Device, Devices where activity can be migrated to
History	Previously visited, new	Landmarks, facilities	Previous events	Friends, prior interactions	Devices where activity migrated to, Preferred devices
Physiological State	Zone in Smart Home	Nearest Sensor /Appliance	Time, day, date	Current inhabitants	Active sensor(s), compatible devices

3 Related Work

There are numerous definitions of context which support the creation of context-aware applications. Schmidt [3] defines context as a situation and the environment a device and user is. Context is identified by a unique name and has a set of relevant features. Though the definitions of Dey and Schmidt are both incomplete with respect to context-aware healthcare, they complete each other. Heterogeneous sensors, devices and actuators exist in a ubiquitous computing environment, making context-aware systems one of the important services for applications. System designers face many challenges while building a framework for such an environment. The key challenge is to engineer a framework capable of adapting to such a highly chaotic environment and seamlessly integrate itself with the existing legacy systems. Many of the middleware are designed as an Event-Condition-Action (ECA) approach [4]. Importance has to be given to the relevance of data pertaining to a situation. It would be more advantageous taking a user's behavior as an entity and deriving work flows from it, rather than considering events as a basal unit [5]. The middleware should be able to predict the information required for a particular service. Hence, the system needs to be imbued with an inherent sentience [6] about their relevant contexts that can automatically or implicitly sense information about their state and users who are present, and thus take action on those contexts. Past works such as the Reactive Room [7], Neural Network House [8], Intelligent Room [9], and House_n [10] do not provide explicit reusable support for users to handle or correct uncertainty in the sensed data and their interpretations, and assume that the contexts being sensed are unambiguous. These approaches, however do not consider user privacy in their design.

Privacy is the ability of an individual or group to keep related information, their social and behavioral patterns out of public view, or to control the flow of information about themselves. The perception of privacy in the aspects of the information receiver, user and sensitivity in terms of design was investigated in [11]. Traditionally, privacy enhancing technologies [12] have been thought as tools for hiding, obfuscating, and controlling disclosure. But in terms of an overall approach to privacy management, it is necessary think about how technology can be used to create visibility and awareness of information security practices. Tentori et al. [13], introduced the concept of Quality of Privacy to address the trade-off between the services provided by a ubiquitous environment and the cost that the users might need to pay in regard to privacy. Though this scheme incorporated context-aware communication, the system was not suggestive and depended on the user's knowledge of information sharing. Confab [14] offers a framework where personal information is captured, stored and processed on the end-user's computer as much has possible. Though this addresses the high-level requirements of decentralized architecture and plausible deniability, and offers a larger amount of choice and control than previous systems, the system is not obtrusive in nature. A study of the relationship between context and privacy was made in [15]. [16] presented an architecture for privacy-sensitive ubiquitous computing, where the authors claim that the large majority of work on privacy has tended to focus on providing anonymity rather than considering the many scenarios in everyday life, where people want to share information. Owing to the nature of privacy, it is difficult to design privacy-sensitive ubiquitous applications. In human-computer interaction, computer transparency is an aspect of user friendliness which relieves the user of the need to worry about technical details. When there is a large gap between user perception and actual authentic information, the system is failing in representation of information. Information transparency changes behavior [17], and some efforts have been made in the field of privacy enhancing technologies that help create transparency of information security practices.

4 Challenges of Designing Middleware for Healthcare

Lederer et al., discussed five pitfalls that a designer faces while incorporating personal privacy in a ubiquitous computing environment in [18]. When we consider privacy enhanced context-aware middleware for assisted healthcare, we face three major challenges, specific to privacy enabled context-awareness in the healthcare domain. In this section, we take a look at these challenges that developers face.

4.1 Flexibility for User Preferences and Privacy

Traditionally, designers have adapted two approaches to introduce user preferences and privacy into systems: user-centric and system-centric approaches. In the user-centric approach, the user chooses the rules and settings for the behavior of information contained in the system. In the system-centric approach, rulesets and policies ordain the privacy settings. The user-centric approach is more flexible and transparent, allowing the user to possess knowledge of the information and their privacy levels. However, the privacy setting in such an approach is based primarily on the user's inference of the information stored in the system and understanding of the repercussions of making information transparent to others. In cases of healthcare and other sensitive data, the user might not be aware of the standards and practices involved in disclosure of information, and the privacy settings primarily depend on the awareness and preference of the user. On the other hand, the system-centric approach, policies are generated, based on standards and privacy is set based on the rulesets pertaining to different situations. This approach, however, proves to be rigid in nature, and the user seldom has the option of altering the privacy setting.

Since assisted healthcare systems are predominantly user-based systems, we need to find a trade-off between these two approaches and develop a dynamic approach which includes the flexibility of user-centric privacy modification, along with the policies and rulesets of system-centric privacy. The privacy of information, therefore, should be modeled in a dynamic way taking the context of the system into consideration. The current situation, environment, neighboring users, and other context elements should influence the privacy settings of the system.

4.2 Decision Making

Decision making is crucial in any system for assisted healthcare. The property of Event-Condition-Actions (ECA) often becomes inadequate in these applications, where combinations of multiple contexts and user actions need to be analyzed over a period of time. Context-awareness is considered as a desirable property to overcome this limitation. There are predominantly two types of context that such systems have to resolve in assisted healthcare: *Unambiguous context* and *Ambiguous context*. Unambiguous context can be resolved by developing policies. Though developing rule sets and implementing them as policies is not difficult, there could be situations where the system might encounter situations not encompassed by the policies. The situations in a real world are often dynamic and unfold over time. As a consequence, the dynamic aspect of healthcare generates ambiguous context. Therefore, it would be necessary to implement a decision engine to complement the rules engine. When the system does not find any rule pertaining to the current context, it transfers the obtained information and knowledge to the decision engine, which is a predictive framework and based on the belief functions, a probabilistic model is generated, allowing the system to develop a policy for the new context.

Additionally, an explanation function has to be incorporated into the system to explain the rationale behind tagging a certain event as necessitating attention. Physicians could look at the explanation and instruct the developers to make changes to the function, thereby refining the guidelines and rules stored in the knowledge base. This enables the system to improve its accuracy of prediction and decision making.

4.3 Context Privacy

A frequent definition of information privacy is “the claim of individuals, groups, or institutions to determine for themselves when, how, and to what extent information about them is communicated to others” [19]. Despite this definition,“not sharing information” is a fundamental aspect of privacy. The real privacy concerns people have today revolves around who has access to what information rather than what information is collected. A major portion of previous work on privacy has focused on anonymizing user information or on preventing adversaries from obtaining personal information and messages. Though anonymity and security are a priority, they focus on some issues of privacy and do not completely handle many situations where the users choose to share information with others. Existing approaches to supporting user privacy focus largely on conventional data management schemes. However, due to the highly dynamic nature of user data, Context awareness is a key issue in ubiquitous computing environments and has to be addressed in a user-centric manner. This implies that privacy depends not only on sets of rules to resolve situations, but also on the granularity of user-specific privacy levels. This calls for development of a context-aware system which conveys the implications of privacy to the users in a lucid manner.

5 Conclusion

In this paper, we have investigated various interpretations of context and analyzed some popular definitions of context in ubiquitous systems. We have also attempted to prove a more comprehensive definition of context, incorporating passive or active interaction of an entity in an environment, interpreting the obtained information as knowledge, enabling us to perceive the state or environment better, and allow inference of future states based on this perception. We have also presented some major challenges that designers face while developing privacy enhanced context-aware ubiquitous computing systems for assisted healthcare.

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Safety-Ensuring Systematic Design for Service Robots

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Abstract. A safety-ensuring systematic design procedure is proposed that allows service robots to be designed to perform predefined tasks in which safety is guaranteed. To cope with the safety problem, the safety target is defined, the hazards associated with predefined tasks are identified, and the risks are analyzed. In addition, the proposed method considers risk reduction measures in all steps of robot design and verifies whether the safety target is achieved. Through the use of the proposed design procedure, it is shown as an example that a care-providing robot for physically disabled people can be designed.

Keywords: Service robot, Safety-ensuring design, Reliability, Risk analysis, Target-Oriented Design (TOD).

1 Introduction

This paper presents a safety-ensuring systematic design methodology for service robots and a simple case study of the design of a safe care-providing robotic arm. Provided below are the background and context associated with this endeavor.

The introduction of robots in the daily lives of people raises a key issue that is added to the standard challenge of autonomous robots: the presence of humans in the robot environment and the necessity to interact with them. As it is mandatory to consider human safety in such applications, the design of a service robot is substantially different from that of an industrial robot. Moreover, the *traditional safety methods for industrial robots are not adequate for service robots*. The use of service robots, especially when the tasks of the robot are performed near or in contact with a human, has a critical impact on people when errors arise. Thus, *safety aspects must be considered in all steps of the design*.

There are several studies of safety considerations in robot design. Regarding physical safety, lightweight robots are considered to reduce the possibility of injury due to impact [1-3]. In the case of a collision, the lighter links display lower inertia and thus lower energy is transferred to a human during an impact. In addition, several studies have introduced mechanically compliant elements such as those in joints [4,5] or between the actuator and the joint [6,7] of a robot. Soft visco-elastic covering to the robot link is also considered [8,9]. These compliant elements and soft covers are useful as type of protection against unexpected contact during physical human-robot interactions. There are several joint actuation schemes, including the variable- impedance transmission [10] scheme and the distributed macro-mini actuation [11] scheme.

S. Helal et al. (Eds.): ICOST 2008, LNCS 5120, pp. 208–217, 2008.

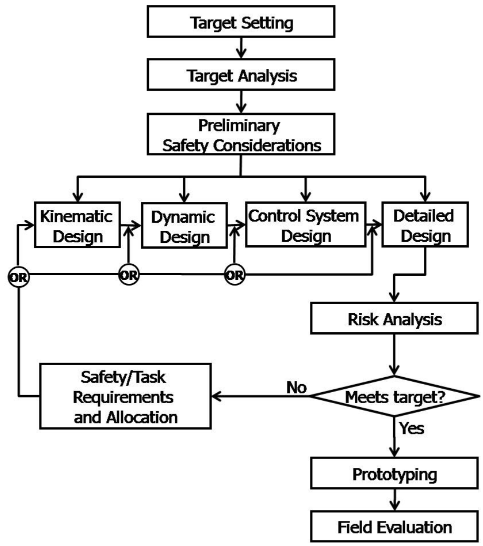

Fig. 1. Safety-ensuring systematic design procedure for service robots

Previous research works have focused on dynamic design aspects of robots, such as reducing the weight and inertia of a robot, or on detailed design aspects such as introducing mechanical compliance, soft covering and new joint actuation schemes. These studies have considered *only limited aspects of safety* and are limited as well to *a specific area of the overall robot design procedure*. Other parts affecting safety, such as kinematic design and the reliability of robot components, have not been considered as much in the research. In this way, there is *no research work to consider the overall robot design steps systematically affecting human safety*.

Additionally, the safety criteria are not established; thus, whether the safety level is enhanced is unknown. *There is no reliable means of discovering whether the designed robot is actually safe or if it performs its tasks while guaranteeing an acceptable level of residual risk*.

To cope with these problems, *an overall safety-ensuring robot design methodology with consideration of safety criteria, risk analysis and task performance is necessary*. With this methodology, all safety aspects can be considered in all steps of robot design, and the safety-ensuring robot can be designed in a systematic and effective way.

In this paper, a safety-ensuring systematic design procedure for service robots considering both task execution and safety aspects is presented. For the former concern, a task-oriented design approach [12] is utilized; for the latter, the safety lifecycle of International Electrotechnical Commission (IEC) 61508 [13] is adopted as a safety-considering framework. Thus, by combining two approaches, it is possible to consider both the task and the level of safety. The proposed design procedure is described in Fig. 1.

In Section 2, the proposed overall design procedure is presented in detail. Section 3 provides a simple design example of a care-providing robot. Finally, the conclusion and directions for future research in this area are discussed in Section 4.

2 Safety-Ensuring Systematic Design for Service Robots

2.1 Target Setting

As the first step of safe service robot design, a set of targets that includes the target tasks, target people and target environment and target safety should be defined. It is the conviction of the authors that this step, being the basis of all subsequent steps, is the most important and should be determined as clearly and concretely as possible [12].

Target tasks are drawn from the tasks that the service robot should perform. Target people are the humans for whom the robot is supposed to perform target tasks. The target environment is a detailed environment in which the robot will perform the target tasks for the target people. Target safety refers to the desired safety level when the robot performs the target tasks for the target people in the target environment. Target safety is defined considering the risk associated with the hazards when the robot performs the target tasks. Risk is composed of the consequences and probability of the hazard. Primarily, the robot should be designed to protect against component failures, i.e., the robot system should be designed to be highly reliable. Secondly, the robot should be designed to protect humans from serious injury. In general, the target safety is determined according to the designer or in line with legislated standards. In this paper, the target safety is determined by the designer using the Safety Integrity Level (SIL) of the IEC 61508 standard. IEC 61508 specifies four levels of safety performance for a safety function known as SILs. They are described in Table 1. This concept is adopted to set up safety target such as the example discussed in Section 3.1. The target safety is more rigorous at higher levels of safety integrity in order to achieve the required lower likelihood of failure. Target safety requirements are composed of reliability requirements according to the severity categorization of the hazard, as shown in Table 2.

2.2 Target Analysis

Task Analysis [12]. In order to design a safety-ensuring service robot for predefined tasks, it is necessary to describe the tasks quantitatively. To this end, these tasks should be analyzed to obtain the following entities: via points, task execution time and the maximum payload. Of these, via points are used for the kinematic design of the robotic arm, whereas the rest are required primarily for dynamic design. More details are described in the literature [12].

Hazard Identification. A hazard is any potential source of damage or injury to the target people. The hazards for a service robot in terms of its target people and in its environment should be identified by the robot designer. The hazard identification process determines what must be done to avoid the hazardous events associated with the target tasks and whether safety requirements are necessary to ensure adequate protection against each hazard. After identifying the hazards, the safety level in the performance of each target task can be defined in order to protect against the hazard. For the safety level, safety requirements are determined in the preliminary safety considerations step and the safety/task requirements and allocation step.

Table 1. Safety Integrity Levels (SILs)

Safety integrity level	Probability of dangerous failure per hour
4	$\geq 10^{-9}$ to $< 10^{-8}$
3	$\geq 10^{-8}$ to $< 10^{-7}$
2	$\geq 10^{-7}$ to $< 10^{-6}$
1	$\geq 10^{-6}$ to $< 10^{-5}$

2.3 Preliminary Safety Considerations and Kinematic / Dynamic / Control System / Detailed Design

Preliminary Safety Considerations. In this step, safety is considered in a well-known intuitive manner. A shorter link length, lighter mass, smaller inertia, lighter material and round shape rather than a sharp edge will be safer when the robot comes into contact with the human body. The use of highly reliable components in a robot system will make the robot system more reliable, although this trend also incurs additional costs. Covering a robot arm with soft material is a strategy that reduces the impact force when the robot collides with a human.

Kinematic Design [12]. In the kinematic design, the goal is to determine a kinematic structure that realizes the task space obtained in the target analysis step. To this end, it is necessary to determine both the degree of freedom and kinematic parameters of the robot to be designed. For the kinematic parameters, the Denavit-Hartenberg (DH) parameters [14] are adopted. These are obtained through an optimal kinematic design algorithm known as the Grid Method [15].

Dynamic Design [12]. Dynamic design consists of planning the physical construction of the load-carrying parts of the robot. Specifically, this step includes specifying the shape, cross-section, and materials used for each link of the robot and specifying the actuator sizes and transmissions. Dynamic simulations should be conducted to determine the actuator and transmission specifications and to estimate the maximum torque at each joint when the robot performs the predefined tasks. Several aspects are considered, including the execution time and the maximum payload for each task as obtained in Section 2.2. The optimally determined kinematic structure and the estimated values of the mass, mass center and moment of inertia of the links and motors are also taken into account.

Control System Design. The control system design includes the selection of the quantity and type of processor(s), the memory and main-board used in the control system, the selection of the AD/DA/DAq board, the selection of the position sensor and its resolution considering the target tasks, and the selection of the motor driver.

Detailed Design. Detailed design includes details of the fabrication of the robot structure; selection of the bearings for each joint, the mounting of the bearings, sensors and actuators; the formulation of a method and a procedure for the assembly of the robot; provision for the shear pins, break-away joints, and other mechanical features to minimize the potential for self-destruction by the robot; the creation of a 3-D model for the preparation of the manufacturing stage; and a soft cover or compliant joint design to ensure the safety of the robot.

2.4 Risk Analysis, Verification and Safety/Task Requirements and Allocation

Risk Analysis. In this step, risk assessment should be performed for each hazard that was determined in Section 2.2. According to IEC 61508, risk is derived from a combination of the severity of the potential harm and the probability of the occurrence of a hazardous event.

In this paper, the hazards due to the failure of the components of a robot are considered. Thus, it is necessary to estimate the failure rate of each component of each subsystem. To this end, fault tree analysis (FTA) of the robot system is used to determine the causes of potential hazards. In order to consider the severity of harm, the procedure of the failure mode and effects analysis (FMEA) is utilized. If the severity of a hazard is high, more rigorous SILs are adopted. The initial and residual risks are then calculated.

Verification: Does the Designed Robot Meet the Target? When carrying out this step, it is necessary to verify the reduction of the residual risk of the robot and the ability of the robot to perform its target tasks. If the target is not satisfied, the plan shifts to the safety/task requirements and allocation step iteratively. If the target is satisfied, the plan shifts to the prototyping step and manufacturing begins.

Safety/Task Requirements and Allocation. For a reduction of risk, an inherently safe design should be initially considered to remove the hazards or limit the risks. This includes removal of sharp edges, minimizing kinetic energy, and observing ergonomic principles. Against hazards that cannot be avoided or sufficiently limited by an inherent safe design, safeguards should be applied, such as fixed guards, movable guards and brake devices that stop the robot when hazards occur. After the risk reduction process, the residual risks are reassessed in the risk analysis step.

2.5 Prototyping and Field Evaluation

After the verification step, manufacturing of the robot commences and the robot is tested with its target people. If the test result is not satisfactory after a field evaluation, the target setting step is revisited and the design procedure begins again.

3 Case Study: A Care-Providing Robot

The proposed design methodology can be applied to wide areas of service robots. In this section, an example of an application of the proposed methodology is presented. A robot system that cares for disabled people and executes their daily tasks at the home of the person is considered. The care-providing robot in this study is known as KARES II [12,16]. In this case study, the focus is on a shaving task out of the 12 predefined tasks. This involves contact with the face of the disabled person and presents a clear and simple example of a safety-ensuring design. As this task involves contact with the face, safety considerations should be considered in the design procedure.

3.1 Target Setting

The set of target is defined here as follows: target people are people with C4 or C5 injuries, the target task is a shaving task, the target environment is a home and the target people are sitting in a wheelchair. Target safety information is summarized in Table 2 according to the severity categorization of hazards.

Table 2. Categorization of Severity and Target Safety Levels

Severity categorization	Severity description	Target safety level
Catastrophic	Possibility of death	SIL 3
Critical	Possibility of severe injury	SIL 2
Marginal	Possibility of minor injury	SIL 1

3.2 Target Analysis

Task Analysis. In this example, a via point has six coordinates: three for the position and three for the orientation of the tool. After having obtained all the via point sets for the predefined tasks, a union of all sets was created in order to define the task space or workspace that is realized in the kinematic design step.

The scenario that describes the process of the shaving task is as follows:

1. The robot arm is at its initial configuration.
2. The robot arm grasps the electric shaver that is initially on a table.
3. The robot arm holding the shaver in its gripper approaches the chin of the target person.
4. The robot arm holds the position while the target person shaves.
5. After finishing the shave, the robot arm places the electric shaver on the table.
6. The robot arm moves to its initial position.

Hazard Identification. From the scenario of the shaving task, two hazards associated with the shaving task can be identified, as follows: Hazard 1) The robot arm collides with the target person when it operates during the third step of the scenario; Hazard 2) The robot arm is driven at an excessive contact force when it makes contacts with the target person during the fourth step of the scenario. Therefore, the safety definition of the shaving task is defined as follows: When the KARES II robot performs the shaving task on C4-type handicapped people in a wheelchair using an electric shaver, safety is defined as protecting the people from the moving robotic arm and from excessive contact force under the target safety level.

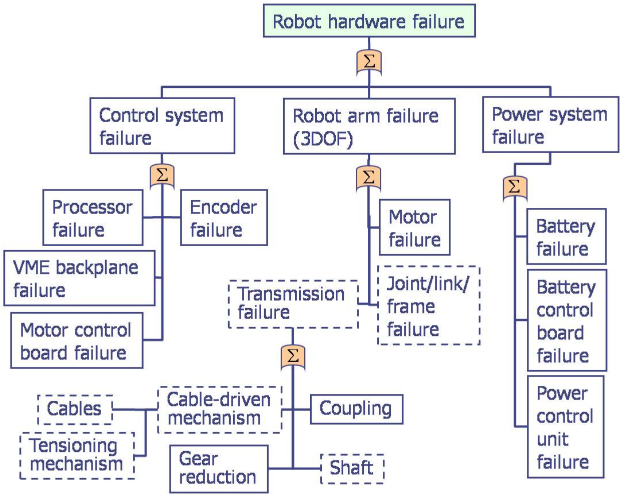

Fig. 2. Fault tree analysis of the KARES II robotic arm hardware part (Dotted blocks were not considered when calculating the robot failure rate)

3.3 Preliminary Safety Considerations and Kinematic/Dynamic/Control System/ Detailed Design

Preliminary Safety Considerations. For protection from the moving robotic arm, the robot should have short links, low mass/inertia, a round shape, lightweight material and compliant elements. For protection from excessive contact force, the robot should be designed to sense the contact force and to limit excessive torque exerted by the actuators.

Kinematic Design. To perform the shaving task, a 6-DOF manipulator is needed. Revolute joints were chosen for the first three joints and a spherical joint is used for the wrist joints. The optimized DH-parameters were determined using the Grid Method while considering the short links.

Dynamic Design. Cylinder-shaped links were chosen along with aluminum alloy material to reduce the weight of the robotic arm while preserving its strength. Lighter materials such as carbon fiber can also be used. In order to reduce the weight of the links, several commercial stress analysis software packages, including those known as visualNastran and ADAMS were used. The maximum torque at each joint, the motor/ transmission specification and the link diameter/link thickness were determined through iterations as they are related.

Control System Design. The resolution of the position sensor was specified. As none of the predefined tasks demands the high speed and accuracy of an industrial robot, a 1000 pulse-revolution optical encoder was deemed to provide more than sufficient accuracy for the tasks. In order to assess the reliability of the control system in the risk analysis step, control systems such as the processor, the VME backplane and the motor control boards were identical to those in an earlier study [17].

Detailed Design. Detailed design of the entire robotic arm was created using the graphical modeling software known as Solid Edge.

3.4 Risk Analysis, Verification and Safety/Task Requirements and Allocation

Risk Analysis. In this case study, the scope of risk analysis was limited to the robot hardware parts. Using FTA, the likelihood of robot hazards due to the failure of the robotic components was identified. Some of the failure rates in Table 3 were derived from RIAC databooks [18,19] which are commonly used for reliability predictions in aerospace and military applications. The other failure rates in Table 3 were sourced from the literature [17]. Using the reliability background in the literature [17], FTA as described in Fig. 2 and failure rates for robot components shown in Table 3, it was possible to calculate the initial failure rate of the robot hardware. The result is shown in Table 4.

Table 3. Failure Rates for Robot Components [17, 18, 19]

Components	Failure rate(1/h)	Components	Failure rate(1/h)
Processor	8.6×10^{-7}	Encoder	1.5×10^{-6}
VME backplane	4.49×10^{-6}	Battery	2.1×10^{-7}
Motor control board	3.4×10^{-5}	Battery control board	4.0×10^{-7}
Motor	6.4×10^{-6}	Power control unit	1.9×10^{-7}

Table 4. Calculated Failure Rates for Robot Subsystems

Subsystem	Failure rate for initial system	Failure rate considering safety
Control system	4.38×10^{-5}	4.00×10^{-7}
Robot arm	1.92×10^{-5}	7.95×10^{-10}
Power system	8.00×10^{-7}	4.95×10^{-7}

Table 5. Failure Mode and Effects Analysis (FMEA) of Robot Hardware Part

Subsystem	Component	Failure modes	Effects on robot	Severity level
Control system	Processor VME backplane Motor control board	Short circuit Burnout	Wrong control input User may be unable to control the robot Robot could hit and injure the user	Critical → Target risk is SIL 2.
Robot arm	Motor Encoder Transmission Joint/Link	Brush/bearing failure Sensing part failure Mechanical failure	Insufficient or excessive motor output Wrong position/ orientation information Robot could hit and injure the user	Critical → Target risk is SIL 2.
Power system	Battery Battery control board Power control unit	Power failure	Robot could fall due to gravity Robot could hit and injure the user	Critical → Target risk is SIL 2.

Verification. From Tables 4 and 5, the initial failure rate does not satisfy the target safety of SIL 2. As the target safety is not satisfied, the safety/task requirements and allocation step is revisited and the risk analysis step and verification step are iteratively revisited until the target is satisfied.

Safety/Task Requirements and Allocation. From Table 4, the risks associated with the control system and robot arm must be greatly reduced. There are several measures that can reduce the risk in the control system, such as the use of a more reliable motor control board, VME backplane and processor and the addition of a motor control board and a redundant encoder into the control system. If the same motor control board and encoder are added in parallel to operate the motor correctly if the other motor control board and encoder fail and if a 20x more reliable VME backplane and a 5x more reliable processor are used, the failure rate of control system then becomes 4.00×10^{-7}.

For risk reduction in the robot arm, an electromechanical brake can be used. If such a brake is added to each joint of robot arm, the brake will hold the robot arm when motor failures occur. In the RIAC databook [19], there is an electromechanical brake with a failure rate of 4.14×10^{-5}. If such brakes are added to each joint, the failure rate of robotic arm then becomes 7.95×10^{-10}. To reduce the risk in the power system, a battery control board and battery that are twice as reliable as the original systems are used. In this case, the failure rate of the power system becomes 4.95×10^{-7}.

Iteration: Risk Analysis and Verification Steps. From Table 4, the newly calculated failure rate of the robot hardware is 8.95×10^{-7}, which satisfies the target safety of SIL 2. Verification of whether the designed robot can perform the target task using a 3D model built in the detailed design steps with commercial dynamic simulation software is now possible. Considering the risk reduction measures in previous steps, the risks that should preferentially be reduced or the safety considerations that will provide cost-effective performance should be considered.

4 Conclusion

In this paper, a safety-ensuring design methodology is proposed and it was applied to a care-providing robot, step by step, following the procedures described in Section 2. Using the proposed methodology, a safety-ensuring robot can be designed in a systematic and effective way without requiring unnecessarily numerous iterative steps or involving substantial time, effort or overhead.

In this paper, the safety concern is limited to the hardware parts of the service robot system. In the future, the software and communication parts of the robot system should also be considered. Moreover, the severity of injuries should be considered in a quantitative manner.

Acknowledgments. This work was supported in part by the Korea Science and Engineering Foundation (KOSEF) and Human-friendly Welfare Robot System Engineering Research Center (HWRS-ERC). Authors are gratefully acknowledging the financial support by Agency for Defence Development and by UTRC (Unmanned Technology Research Center), Korea Advanced Institute of Science and Technology.

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