Bessam Abdulrazak Sylvain Giroux
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Volume Editors

Bessam Abdulrazak
Sylvain Giroux
Hélène Pigot
Université de Sherbrooke
2500 boulevard de l'Université, Sherbrooke, Québec, Canada, J1K 2R1
E-mail: {bessam.abdulrazak, sylvain.giroux, helene.pigot}@usherbrooke.ca

Bruno Bouchard
Université de Québec à Chicoutimi
555, boulevard de l'Université, Chicoutimi, Québec, Canada, G7H 2B1
E-mail: bruno.bouchard@uqac.ca

Mounir Mokhtari
Institut TELECOM/TELECOM SudParis, France
and CNRS IPAL (UMI 2955), Singapore
Institute for Infocomm Research (I2R A-Star)
1 Fusionopolis Way, #21-01, Singapore 138632
E-mail: mounir.mokhtari@it-sudparis.eu

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Preface

Smart environments are augmented environments capable of utilizing embedded computers, information appliances, micro/nano systems and multi-modal sensors, in which computational intelligence is ubiquitous to provide contextual, proactive and personalized services to people. Nowadays networks, microprocessors, memory chips, smart sensors and actuators are faster, cheaper and smaller. They are becoming pervasive in the physical environment. Current advances in such enabling technologies make it possible to build real smart environments and hence provide the opportunity for novel applications and services to be delivered for improving the quality of life and health of people at home and outside. A smart environment allows people to perform tasks efficiently by offering unprecedented levels of access to information and assistance. In the near future, the elderly and people with disabilities will avail of smart assistive technology to assist in carrying out daily activities, socializing, enjoying entertainment and leisure activities all while maintaining good health and well-being. These smart environments are complemented by the role of health telematics. Health telematics approaches utilize advanced networks and telecommunication technologies to provide healthcare remotely. Combined with ubiquitous technologies in smart environments, health telematics can radically transform the way health-related services (diagnosis, therapy and assistance) are conceived and delivered.

In 2003, Mounir Mokhtari organized in Paris the first of what has become a well-known series of conferences on Smart Homes and Health Telematics (ICOST). ICOST is a premier venue for presenting and discussing research in the design, development, deployment, evaluation and understanding of smart environments as well as assistive technologies and health telematics systems. ICOST gathers research from interdisciplinary fields that develop, utilize, integrate and evaluate embedded computers, information appliances, micro/nano systems, and multimodal sensors, where computational intelligence is ubiquitous to provide contextual, proactive and personalized applications to foresee services for improving the quality of life and health of people inside and outside their home.

Over the years, ICOST conferences succeeded at creating an active research community dedicated to exploring how smart homes in particular and health telematics in general can foster independent living and an enhanced life style for elderly and disabled people. A long and enriching journey has thus led to the ninth edition of ICOST that was held in Montreal, Canada, during June 20–22, 2011. The theme of this edition was "Toward Useful Services for Elderly and People with Disabilities." The backbone of the 2011 edition was built on the stimulating and thought-provoking presentations of four keynote speakers and 25 full papers selected from the 94 that were submitted. These papers are organized in the following thematic chapters: Smart Home and Village, Health Telematics and Healthcare Technology, Well-Being, Ageing Friendly and

Enabling Technology, and finally Medical Health and Healthcare Technology. To provide PhD students a forum to promote their research and an opportunity to network, a student session involving eight papers was added. Finally, 17 posters complemented with short oral presentations were hosted. Furthermore, for the first time an ICOST summer school was held jointly with the conference.

We would like to thank all the people that were involved in the making of this conference, in particular members of the Steering Committee for their assistance and valuable feedback, members of the Program Committee for their in-depth and timely reviews of papers, members of the Organizing Committee for their incredible contributions and unremitting efforts, and finally the keynote speakers, the authors and the attendees for their contributions and participation to the conference. They all contributed to turning the 2011 edition of ICOST into an exciting and challenging conference.

June 2011

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Adaptative Applications for Heterogeneous Intelligent Environments

Aitor Almeida[1], Pablo Orduña[1], Eduardo Castillejo[1], Diego López-de-Ipiña[1], and Marcos Sacristan[2]

[1] DeustoTech –Deusto Institute of Technology, Universidad de Deusto
Avenida de las Universidades 24,
48007 Bilbao Spain
{aitor.almeida,pablo.orduna,eduardo.castillejo, dipina}@deusto.es
[2] Parque Tecnológico de Asturias Parcela 30
E33428 Llanera Asturias Spain
marcos.sacristan@treelogic.com

Abstract. As the device ecosystem in the intelligent environments becomes more complex, the need for supporting a wider range of devices becomes crucial. To address this challenge, this paper describes a framework, Imhotep, which can be used to develop mobile applications, easily adapting them to the constraints imposed by the user and device capabilities through a set of preprocessor directives. These directives are enhanced with concepts that are automatically adjusted to the current trends of mobile devices by using a fuzzy knowledge-eliciting reasoner.

Keywords: Adaptation, intelligent environments, fuzzy logic.

1 Introduction

Modern homes host a technological ecosystem composed by heterogeneous devices with a wide range of capabilities and characteristics. Developing applications for these kind of scenarios presents a set of challenges that make difficult for developers to create applications that can reside in any of these devices. This problem reaches new dimensions when developers start considering not only the different devices, but also users. Users also possess a wide variety of abilities (sensorial, cognitive…) that make difficult to target every group with one application. In our research group's[1] previous work our main focus has been the development of server-side applications [1, 2] to create intelligent environments that react to the changes in the context. In these projects we have neglected the client side of the intelligent environment applications, but we acknowledge that users are a central element in intelligent and assistive environments. The devices employed by users to interact with the environment are as diverse as the users themselves, providing a wide range of possibilities.

[1] http://www.morelab.deusto.es/

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To tackle this problem we have created a framework for developers that facilitates the creation of applications adapting them to the device that are going to run into. The framework allows developers to state how their applications should react to the different device characteristic. What is more, it simplifies the development process, so developers without previous experience with mobile devices can use more natural expressions to define the capabilities of the devices. To do so the framework uses a fuzzy inference engine along trend metrics to characterize the mobile devices. The framework also provides an application server that stores the program and adapts it to the target device when a new installation request is received. We have previously employed this approach [12] to create user interfaces adapted to the capabilities of the user. This solution is by some means similar to the different repositories developed by the mobile operating system manufacturers. Apple started the App Store in July 2008, Android Market was available to users in October 2008, Blackberry published App World in April 2009, Nokia launched Ovi Store in May 2009 and Microsoft released the Windows Phone Marketplace in October 2010. Third-party developers can use these software repositories to upload their applications and publish them to the final customers. Applications have to deal with its own customization dynamically, checking the constraints of the devices on which they are being executed. Therefore, developers cannot upload a customized build for each user optimizing the bandwidth and the space on the phone, in contrast to the approach presented in this paper.

2 Related Work

Application adaptation has already been used in other areas. In [4, 5], authors developed a middleware to adapt services to context changes based on a user-centric approach. In [6], authors describe a mechanism to adapt the user interface to some physical characteristics of the user like his height or the distance to the screen, without a special emphasis to the disabilities. In [7], the authors defined a context model for information adaptation that takes into account the user needs and preferences.

In order to select one approach for the creation of adaptative applications we have analyzed the techniques used by different frameworks: Custom mark-up languages (as those used by OpenLaszlo [8]), use of factories (like Google Web Toolkit [9] and EMI2lets [3]) and the Preprocessor Directives (as used in Antenna [10] and J2ME Polish [11]). All these alternatives have their own strengths and weaknesses. After analyzing the alternatives we have concluded that the approach used by Antenna and J2ME Polish is the most fitting one for our requirements. Decoupling the framework from the programming language provides a versatility not attainable with the other approaches, making the framework suitable to be used in the development of any application. What is more, because there is no need to learn a new language any developer can easily include the necessary directives in his code.

3 Adaptative Application Framework

This section describes the architecture. The Imhotep framework is divided into two general elements: the application server and the mobile client (see Fig. 1). The mobile

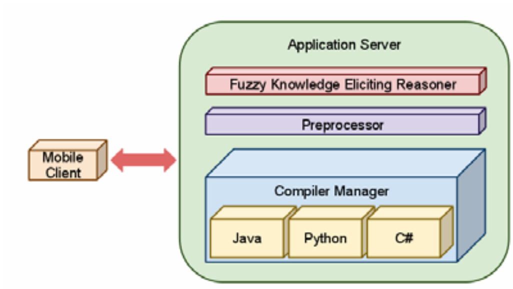

Fig. 1. The adaptative framework is divided in two main elements, the mobile client and the application server

client will perform queries on the application server to search applications available in the repository. With a selected application, the mobile client will request it, providing its characteristics, and the application server will return a customized binary file that the mobile client will deploy. In order to build this customized binary file, the application server will first use the Fuzzy Knowledge Eliciting Reasoner to infer new values taking into account the rules that the developer provided. For instance, the developer could establish concepts such as *"if the memory is higher than 256 MB and the frequency of the CPU is higher than 512 MHz, then COMPUTING_CAPABILITIES are HIGH"*. With these inferred values, as well as with the non-inferred values that the system already had of the device, the application server will use the Preprocessor to parse the application source code. The non-inferred values are directly taken from the WURFL[2] (Wireless Universal Resource File) database, version 2.9.5. WURFL is an open source database containing data about features and capabilities of a large number of mobile devices. We have extracted those relevant variables from the database and imported in the Imhotep one. Finally, the application server will use the Compiler Manager to build the adapted application with the generated source code. Given that these compilations are cached, the full process is executed once per each application and different configuration so when the application had already been compiled the time used is not significant.

3.1 Preprocessor Directives

The code provided by the developer will be annotated with a set of directives that the preprocessor will compute. These directives define how the final source code must be generated, providing conditions for certain regions of code to be added or skipped, and adding Imhotep variables that the preprocessor will adapt for each compilation. Therefore the preprocessor will parse the original annotated source code and will generate the code that will actually be compiled. The preprocessor identifies the directives when they start by //# in languages that support inline comments starting by //, such as Java, C# or C++, #// in languages that support inline comments starting by #, such as Python or Perl, and '// in VB.NET.

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

```
//#if defined(${piramide.devices.height})
   //#if ${piramide.devices.height} > 150 * 2
          addTenRows();
   //#elif ${piramide.devices.width} > 200
         addTenCols();
   //#else
         addFiveRowsAndCols();
   //#endif
//#else
     addFiveRowsAndCols();
//#endif
```

Fig. 2. Preprocessor Directives

The preprocessor can avoid the compilation of fragments of code if certain conditions are matched. These conditions can include calls to functions provided by the system. Basic string and math functions are available, including *lowercase*, *trim*, *contains*, *round* or *sqrt*, as well as functions to check if a certain variable is available. The conditions can be embedded, as shown in Fig. 2. Whenever it is required, developers can directly store in programming variables the system ones. This way, developers can adjust programmatically to the exact values of the variables.

3.2 Fuzzy Knowledge Eliciting Reasoner

The application developer may not be aware of the current state of the device market. For instance, developers might only want to establish high level asserts such as *"is the screen big?"* or *"is the processor fast?"*. However, these asserts depend on the global market of mobile devices at a particular moment. What was considered a big resolution for a mobile device in 2005 is considered a medium screen nowadays, and a fast processor in 2005 might become average or slow today. Furthermore, developers might want to construct higher level asserts combining different capabilities. For example, *"video capabilities"* can be seen as the combination of the screen size, the resolution and the supported video codecs. For this reason we have developed the Fuzzy Knowledge-Eliciting Reasoner. The goal of the Fuzzy Knowledge-Eliciting Reasoner is to identify new capabilities using the already existing ones and to fuzzify them. To do this we have defined a set of fuzzy rules that take numeric values from the existing capabilities as input and create symbolic values for the new ones. An example for the reasoning that takes place in this stage would be: "*If the resolution is big and the screen size is big the video suitability is very high*". The main problem we have encountered using fuzzy rules is that we need to fuzzify the crisp variables encountered in the databases (in our case WURFL 2.9.5). This raises some challenging questions. What do we consider a *"big"* screen size? How can we identify what characteristics are inherent of the average mobile device? These concepts are relative to the values of other device models. One screen is big if its height and width are larger than the average values of the other models. But all device models can not have the same weight in the calculation, neither all the device models have sold the same number of units. This is why the most popular models should have more weight during this calculation. In order to calculate the popularity of one device we have to adjust it with its *"age"*. Popularity fades away with the passing of time.

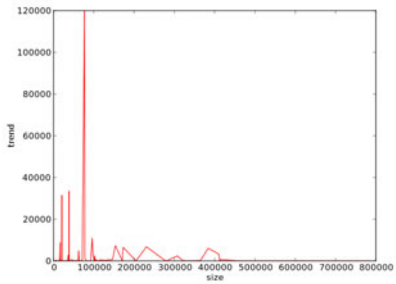

Fig. 3. Popularity calculation for all the resolutions of the mobile devices in WURFL

Users tend to change their mobile phones frequently, drastically altering the perception of what is a big screen from one year to another. Our proposed solution uses Google Trends[3] to identify the popularity of each mobile device. We use the trend information of the last three years (2007, 2008, 2009 and the first 2 months of 2010). While this number does not represent the sale volume, we think that it is a good indicator of the interest shown by the consumers in a specific model. Due to the lack of data regarding the real sale volume for most mobile devices is one of the few available indicators. This trend value can change drastically from one location to another; the most popular devices are not the same in Japan and Spain. To tackle this problem we support the geolocation of the results to filter them according to the needs of the developers.

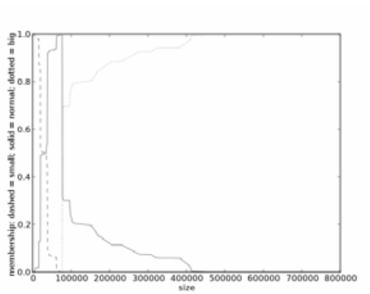

Fig. 4. Membership function for the resolution of the screen using 3 linguistic terms: small (dashed), normal (solid) and big (dotted)

Once the popularity values for all the devices in the WURFL database have been retrieved, the membership functions of the different crisp capabilities are calculated. For example, in Fig. 3 can be seen the adjusted values of popularity expressed in number of searches performed (vertical axis) for the values of the screen resolution represented as the result of multiplying the height and width (horizontal axis). As can be seen in the graph the majority of the population is gathered between 50000 and

[3] http://www.google.es/trends

100000. We use this popularity value to calculate the membership function of each variable (see Fig. 4). In this case the screen resolution has 3 linguistic terms: small (dashed), normal (solid) and big (dotted). Finally we use these membership functions in the fuzzy rules described previously in this section.

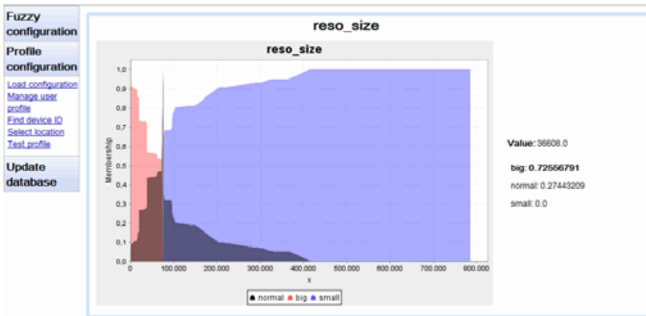

Fig. 5. Testing the generated fuzzy configuration

To ease the creation of the fuzzy rules we have developed a wizard[4] that guides developers during the process. This wizard is web based and has been developed with Google Web Toolkit [9]. Using it, developers can load an XML file with the description of the fuzzy terms, as well as the profile configuration, indicating the capabilities of the user and the mobile device used. The device is chosen from the list of supported mobile devices, taken from the WURFL database. Once the variables and rules have been created the results can be tested, providing a graphic of the generated membership functions (see Fig. 5)

4 Evaluation

In order to evaluate the usability of Imhotep, a survey was performed among software developers not involved in the project with the questions detailed in Table 1, highlighting those with highest votes for each question. At the moment of writing this paper 19 developers have participated in the survey. As it can be appreciated, 73.68% of the developers considered that Imhotep facilitates much (4) or very much (5) the development of accessible applications, and 84.21% considered that it was useful (4) or very useful (5). The time required for learning to use was considered very low (1), and developers considered the directives simple enough (1), although the time required to perform the test was considered medium (3). Finally, most developers considered Imhotep interesting (4-5) for future accessible or device adaptable applications developments.

As part of the evaluation, we have implemented a use case. Previously Imhotep had been used to adapt the graphical user interfaces [12] to the capabilities of the user, providing different interfaces for blind people and for people without visual disabilities. However, as detailed in this paper, Imhotep is also used for facilitating the

[4] www.morelab.deusto.es/imhotep/

Table 1. Evaluation results

Question	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Previous experience in the development of accessible/device adaptable apps (1 – no experience; 5 – experience)	**63**	26	11	0	0
Time used to learn Imhotep (1 – short; 5 – long)	**37**	**37**	16	5	5
Preprocessor directives complexity (1 – low; 5 – high)	**63**	26	5	0	5
Facilitation of the development (1 – low; 5 – high)	5	0	21	**58**	16
Usefulness of Imhotep (1 – useless; 5 – useful)	0	0	16	**68**	16
Time to perform the test (1 – short; 5 – long)	26	21	**37**	16	0
Would you use Imhotep in the future? (1 – unlikely; 5 – likely)	0	5	21	**58**	16

multidevice application development for smart environments. As Fig. 6 shows, an application developed with Imhotep controls different sensors -temperature- and actuators -lights, heating- of a smart room.

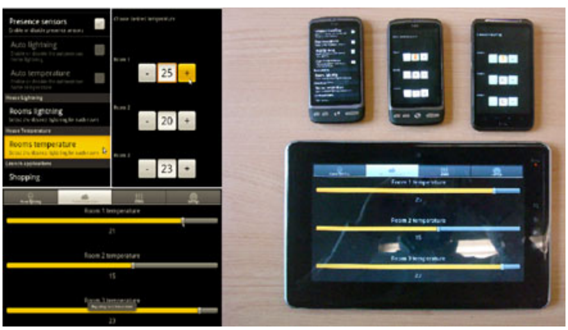

Fig. 6. The same application adapted to HTC Desire and Toshiba Folio 100

This application has been adapted to two different types of devices -a mobile phone and a tablet- so while there is a single project to maintain and the source code is the same, the downloaded binaries are different for each device. The images shown in the tablet will have a higher resolution, requiring more space in disk compared to those downloaded for the mobile phone. Since the Application Server counts with information of the memory and the microprocessor of each device, the developer can ask the application to store more or less data in the ontology used in the smart environment, so an HTC Desire would automatically store less data than an HTC Desire HD. The result is that each device will download an adapted binary of the application with the same behavior but different user interfaces, memory buffer sizes and communications technologies best adapted to the capabilities of each mobile device.

5 Conclusions

This paper has presented a framework that enables the creation of applications suited for different user and device capabilities easily. We have also discussed a fuzzy-logic based inference mechanism that allows identifying new capabilities based on those ones already known. Future work will focus on making Imhotep more developer friendly with the integration of the framework with an IDE. We will also like to merge the data from different databases. Finally we will improve all the membership function calculation process.

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An Automated Prompting System for Smart Environments

Barnan Das[1], Chao Chen[1], Adriana M. Seelye[2], and Diane J. Cook[1]

[1] School of Electrical Engineering and Computer Science
[2] Department of Psychology
Washington State University, Pullman WA 99164, USA
{barnandas,aseelye}@wsu.edu, {cchen,cook}@eecs.wsu.edu

Abstract. The growth in popularity of smart environments has been quite steep in the last decade and so has the demand for smart health assistance systems. A smart home-based prompting system can enhance these technologies to deliver in-home interventions to a user for timely reminders or a brief instruction describing the way a task should be done for successful completion. This technology is in high demand with the desire for people who have physical or cognitive limitations to live independently in their homes. In this paper, we take the approach to fully automating a prompting system without any predefined rule set or user feedback. Unlike other approaches, we use simple off-the-shelf sensors and learn the timing for prompts based on real data that is collected with volunteer participants in our smart home testbed.

Keywords: prompting system; automated prompting; smart environments; sensor network; machine learning.

1 Introduction

With an increasing population of older adults in US [1] and rising trends of human care-giving facilities, assistive healthcare systems have started gaining popularity. A smart-home based prompting system is one such technology that delivers in-home interventions to a user for timely reminders or brief instructions describing the way a task should be done for successful completion. Intuitively, prompts in the context of a smart home environment can be defined as any form of verbal or non-verbal intervention delivered to a user on the basis of time, context or acquired intelligence that helps in successful (in terms of time and purpose) completion of an activity. Prompts can provide critical service in a smart home setting especially to older adults and inhabitants with some form of cognitive impairment.

In this paper, we describe the system architecture and functionality of our automated prompting system for smart home inhabitants named Prompting Users and Control Kiosk (PUCK). Developing automated prompting systems like PUCK requires a unique combination of pervasive computing and machine learning techniques. Using real data collected from our volunteer participants in our smart home testbed, we learn the timing of the prompts. Moreover, we achieve this goal without direct user feedback unlike other existing prompting systems. In addition, a major challenge of dealing with

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a minority of prompting situations while training as compared to a vast majority of situations that do not require a prompt, is highlighted and a prospective solution is proposed.

2 Related Work

Reminder systems have been in existence for quite some time now with different research groups taking their own unique approach to solving the problem. From a machine learning perspective these approaches can be broadly classified into four types: rule based (time and context), reinforcement learning, planning and supervised learning. Most of the early and modern reminder systems are rule based. In this approach, a set of rules is defined based on time, the context of an activity and user preferences. Lim et al. [2] designed a medication reminder system that recognizes the reminders suitable for medication situation. Rudary et al. [3] integrated temporal constraint reasoning with reinforcement learning to build an adaptive reminder system. Although this approach is useful when there is no direct or indirect user feedback, it relies on a complete schedule of user activities. The Autominder System [4] developed by Pollack et al. provides adaptive personalized activity reminders using a dynamic Bayesian network as an underlying domain model to coordinate preplanned events. Boger et al. [5] designed a Markov decision process-based planning system that used video inputs to determine when and how to provide prompts to dementia patients for guidance through the activity of hand washing.

In our current study, we use environmental sensors that do not intervene in people's day to day lives. For the sake of privacy concerns we avoid the use of video or audio inputs. Instead, the sensors used by us are inexpensive and can be deployed in a few hours. Moreover, our system and learning models are not reliant on user feedbacks. In term of learning models, we take a supervised learning approach in order to make the prompts more accurate and the system more robust.

3 System Architecture

PUCK is not just a single device but a framework (Fig. 1) that helps in providing automatic interventions to inhabitants of a smart home environment. In our current work we have been able to reach the phase where the system is able to predict a relative time in the activity when a prompt is required after learning intensively from training data collected over a period of time. We are in the process of using touch screen interface for delivering audio cues along with images that are relevant to the activity for which the prompt is being given. The system architecture of PUCK can be broadly divided into four major modules:

- **Smart Environment:** This is the smart home infrastructure that acts as a testbed where experiments are performed. It has a sensor network that keeps track of the activities performed and stores the data in a SQL database in real time.
- **Data Preparation:** The portion of raw sensor data that would be used by the learning models are collected from the database. Features or attributes that would be helpful in differentiating a "Prompt" step from a "No-Prompt" step are generated.

As there are very few training examples that have "Prompt" steps, we use a sub-module, namely Sampling to generate new and unique "Prompt" examples.

- **Machine Learning Model:** Once the data is prepared by the Data Preparation Module, we employ machine learning strategies to identify whether a prompt should be issued. This module is the "brain" of the entire system where the decision making process takes place.
- **Prompting Device:** This device acts as a bridge between the user or inhabitant and the digital world of sensor network, data and learning models. Prompting devices can range from simple speakers to basic computers, PDAs, or even smart phone (a project that we are currently pursuing).

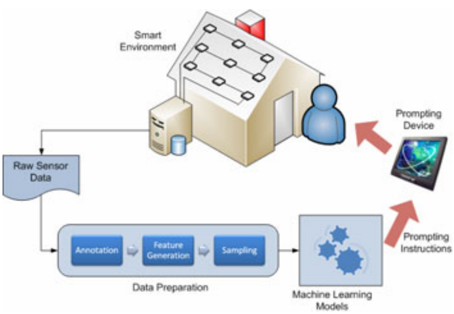

Fig. 1. System Architecture of the PUCK

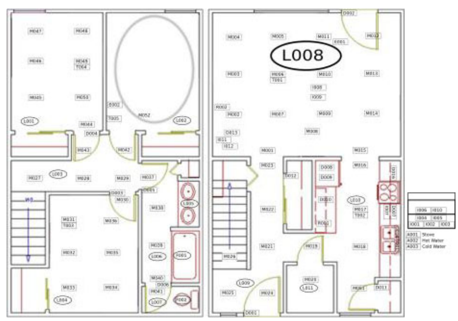

Fig. 2. Three-bedroom smart apartment used for data collection (Sensors: motion (M), temperature (T), water (W), burner (B), telephone (P) and item (I))

4 Experimental Setup

Testbed. The data collection is done in collaboration with the Department of Psychology of the university. The smart home testbed is a 2 story apartment located on the university campus. It contains a living room, dining area and kitchen on the first floor and three bedrooms and bathroom on the second. All of these rooms are equipped with a grid of motion sensors on the ceiling, door sensors on the apartment entrances and on cabinets, the refrigerator and the microwave oven, temperature sensors in each room, a power meter, and analog sensors for burner and water usage. Fig. 2 depicts the structural and sensor layout of the apartment. Data was collected while volunteer older adult participants performed activities in the smart apartment. One of the bedrooms on the second floor is used as a control room where the experimenters monitor the activities performed by the participants (via web cameras) and deliver pre-defined prompts through an audio delivery system whenever necessary. The goal of PUCK is to learn from this collected data how to time the delivery of prompts and ultimately to automate the role of the experimenter in this setting.

The following activities are used in our experiments: Sweep, Refill Medication, Birthday Card, Watch DVD, Water Plants, Make Phone Call, Cook and Select Outfit.

These activities are subdivided into relevant steps by the psychologists in order to track their proper completion. Fig. 3 shows an example of the Cooking task. Participants are asked to perform these specific activities in the smart apartment. While going through the steps of an activity, a prompt is given if he/she performs steps for other activities rather than the current one, if a step is skipped, if extra/erroneous steps are performed, or if too much time has elapsed since the beginning of the activity. Note that there is no ideal order of steps by which the activity can be completed. Therefore, a prompt is given only when one of the conditions mentioned above occurs. Moreover, the goal is to deliver as few prompts as possible. The experimenters keep track of all the errors done by the participants and the steps at which a prompt was delivered, which are later extracted and used to train PUCK.

Cooking

1. Participant retrieves materials from cupboard.
2. Participant fills measuring cup with water.
3. Participant boils water in microwave.
4. Participant pours water into cup of noodles.
5. Participant retrieves pitcher of water from refrigerator.
6. Participant pours glass of water.
7. Participant returns pitcher of water.
8. Participant waits for water to simmer in cup of water.
9. Participant brings all items to dining rooms table.

Fig. 3. Steps of Cooking Activity

```
2009-05-11 14:59:54.934979D010   CLOSE 7.3
2009-05-11 14:59:55.213769M017   ON    7.4
2009-05-11 15:00:02.062455M017   OFF
2009-05-11 15:00:17.348279M017   ON    7.8
2009-05-11 15:00:34.006763M018   ON    7.8
2009-05-11 15:00:35.487639M051   ON    7.8
2009-05-11 15:00:43.028589M016   ON    7.8
2009-05-11 15:00:43.091891M015   ON    7.9
2009-05-11 15:00:45.008148M014   ON    7.9
```

Fig. 4. Annotated data snippet

Annotation. An in-house sensor network captures all sensor events and stores them in a SQL database in real time. The sensor data gathered for our SQL database is expressed by several features summarized in Table 1. These four fields (Date, Time, Sensor, ID and Message) are generated by the data collection system.

Table 1. Sample of sensor events used for our study

Date	Time	Sensor ID	Message
2009-02-06	17:17:36	M45	ON
2009-02-06	17:17:40	M45	OFF
2009-02-06	11:13:26	T004	21.5
2009-02-05	11:18:37	P001	747W
2009-02-09	21:15:28	P001	1.929kWh

After collecting data, sensor events are labeled with the specific activity and step within the activity, {activity#.step#}, that was being performed while the sensor events were generated, as shown in Fig 4.

Feature Generation. From the annotated data we generate relevant features that would be helpful in predicting whether a step is a “Prompt” step or a “No Prompt” step. After the features are generated, the modified form of the data set contains steps performed by participants as instances. This data set is then re-annotated for the prompt steps. Table 2 provides a summary of all generated features.

Table 2. List of Features and Description

Feature #	Feature Name	Description
1	stepLength	Length of the step in time (seconds)
2	numSensors	Number of unique sensors involved with the step
3	numEvents	Number of sensor events associated with the step
4	prevStep	Previous step
5	nextStep	Next step
6	timeActBegin	Time (seconds) since beginning of the activity
7	timePrevStep	Time (seconds) between the end of the previous
8	stepsActBegin	Number of steps since beginning of the activity
9	activityID	Activity ID
10	stepID	Step ID
11	M01 … M51	Frequency of firing each sensor during the step
12	Class	Binary Class. 1=”Prompt”, 0=”No Prompt”

5 Theoretical Background

From machine learning perspective, PUCK works on classification algorithms. The purpose of the classifiers is to predict if a particular step of an activity needs a prompt or not. That is, it can be viewed as a binary class learning problem. However, PUCK delivers prompts only when it is critically important rather than at every possible step, which would make it a cause of annoyance rather than an aid. Intuitively, there are far more "no-prompt" instances in the dataset than "prompt" instances because there are very few situations that would require a prompt. Thus, the data in this domain is inherently skewed or in other words the data has a class imbalance problem.

We use data collected from 128 older adult participants, with different levels of mild cognitive impairment (MCI), to train the learning models. Thus the errors committed by the participants are real and not simulated. There are 53 steps in total for all the activities, out of which 38 are recognizable by the annotators. The participants were delivered prompts in 149. Therefore, approximately 3.74% of the total instances are positive (“Prompt” steps) and the rest are negative (“No-Prompt” steps). This creates a bias in the classifiers to learn more on positive class and thus perform better on them than the negative class. Therefore, performance metrics that measure the classification performance on positive and negative classes independently are considered. True Positive (TP) Rate: represents the percentage of activity steps that are correctly classified as requiring a prompt; True Negative (TN) Rate: represents the percentage of correct steps that are accurately labeled as not requiring a prompt; Area Under ROC Curve (AUC): evaluate overall classifier performance without taking into account class distribution or error cost; and Accuracy (Acc): conventional accuracy of classifiers. Learning models are described in the following:

Decision Tree: A decision tree [6] classifier uses information gain to create a classification model, a statistical property that measures how well a given attribute separates the training examples according to their target classification. In our experiments, we use the J48 decision tree.

k - Nearest Neighbor: The k-Nearest Neighbor is an instance based learning method [7] in which all instances correspond to points in an n-dimensional space. Instance neighbors are calculated using Euclidean distance. For any value of k, the algorithm assigns a class label to a data point that represents the most common value among the k training examples which are nearest to the data point.

Support Vector Machines: Support Vector Machines (SVMs) is a non-probabilistic binary linear classifier [8] that learns a hyperplane or set of hyperplanes which separates a series of positive data instances and a series of negative data instances with maximum margin. Intuitively, a good separation is achieved by the hyperplane that has the largest distance to the nearest training data points of any class, since in general the larger the margin the lower the generalization error of the classifier.

As mentioned earlier, the purpose of PUCK is not to prompt an inhabitant in every step of an activity but to deliver the prompt only for steps where individuals need help to complete the task. Therefore, although the classical machine learning algorithms can have high accuracies, they are not suitable for our purpose as they either fail to predict the steps in which the prompt should be fired or do so with poor performance. In order to resolve this issue we use a technique known as Sampling as described below.

Sampling is a technique of rebalancing the dataset synthetically and can be accomplished by under-sampling or over-sampling. However, under-sampling can throw away potentially useful data, oversampling can overfit the classifier if it is done by data replication. As a solution SMOTE [9] uses a combination of both under and over sampling, but without data replication. Over-sampling is performed by taking each minority class sample and synthesizing a new sample by randomly choosing any or all (depending upon the desired size of the class) of its *k* minority class nearest neighbors. Generation of the synthetic sample is accomplished by first computing the difference between the feature vector (sample) under consideration and its nearest neighbor. Next, this difference is multiplied by a random number between *0* and *1*. Finally, the product is added to the feature vector under consideration. In our dataset the minority class instances are not only small in terms of percentage of the entire dataset, but also in absolute number. Therefore, if the nearest neighbors are conventionally calculated (as in original SMOTE) and the value of k is small, we would have null neighbors. Unlike SMOTE, in our algorithm the k-nearest neighbors are calculated on the basis of just two features: *activityID* and *stepID*. Under-sampling is done by randomly choosing a sample of size *k* (as per the desired size of the majority class) from the entire population without repetition.

6 Experiments and Discussion

All the experiments are evaluated with 10 fold cross validation to see how well the learning models perform at the task of predicting timing (in terms of activity steps) of prompts.

As discussed earlier due to the inherent imbalanced class distribution in the dataset, the classical machine learning algorithms fail drastically on the original dataset. Therefore, we adopt the method of sampling the original dataset. The purpose of sampling is to rebalance a dataset by increasing the number of minority class instances, enabling the classifiers to learn more relevant rules on positive instances. However, there is no ideal class distribution. A study done by Weiss et al [10] shows that, given plenty of data when only *n* instances are considered, the optimal distribution generally

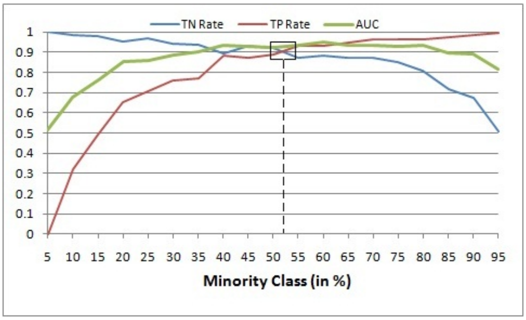

Fig. 5. TP Rate, TN Rate and AUC for different class distributions

contains 50% to 90% of the minority class instances. Therefore, in order to empirically determine the class distribution we consider J48 as the baseline classifier and repeat the experiments, varying percentages of minority class instances from 5% up to 95%, by increments of 5%. A sample size of 50% of the instance space is chosen.

While, any lower size will cause loss of potential information; any higher size will make the sample susceptible to overfitting. From Figure 5 we see that the *TP* rate increases while the *TN* rate decreases as the percentage of the minority class is increased. These two points intersect each other at some point that corresponds to somewhere between 50-55% of minority class. Also, AUC is between *0.923* and *0.934* near this point. Therefore, we decide to choose 55% of minority class to be the appropriate sample distribution for further experimentation.

Three different algorithms, namely, J48, IBk (a k-nearest neighbor algorithm) and SMO are run on the sampled dataset. From Figure 6 (a) it is seen that the *TP* rate has increased tremendously for all the algorithms without compromising too much with *TN* rate (shown in Figure 6(b)). Also the area under ROC curve has also increased (Figure 6 (c)) indicating that the overall performances of all the learning methods have increased. Clearly, sampling encouraged the learning methods to learn more rules for the positive class. But, it should also be noted that average accuracy decreases by a few percentage. This is acceptable till the *TP* rate is high.

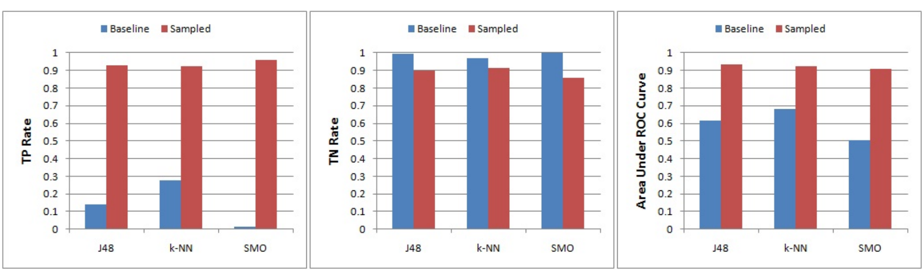

Fig. 6. Comparison of (a) TP Rates, (b) TN Rates and (c) Area Under ROC Curve

5 Conclusion and Future Work

In this paper we described PUCK, a system that automates activity prompts in a smart home environment by identifying the steps at which prompts are required. We discussed the framework in which the prompting system was developed and some challenges faced. We also mentioned some noteworthy properties that are characteristic to the domain of automated prompting.

In our future work, we want to predict the prompts in real time and automating its content. For making PUCK more acceptable to a larger population of older adults and cognitively impaired people, it is essential to determine most appropriate prompt in real time. In a current project we are developing a smart phone prompting interface, as we understand, physical proximity of the recipient to the prompting interface is a crucial factor, and problems like recipient failing to hear the prompts, might be avoided by making a phone the prompting interface that people can always carry with them.

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Domain Selection and Adaptation in Smart Homes

Parisa Rashidi and Diane J. Cook

[1] Washington State University
prashidi@wsu.edu
[2] Washington State University
cook@eecs.wsu.edu

Abstract. Recently researchers have proposed activity recognition methods based on adapting activity knowledge obtained in previous spaces to a new space. Adapting activity knowledge allows us to quickly recognize activities in a new space using only small amounts of unlabeled data. However, adapting from dissimilar spaces not only does not help the recognition task, but might also lead to degraded recognition accuracy. We propose a method for automatically selecting the most promising source spaces among a number of available spaces. Our approach leads to a scalable and quick solution in real world, while minimizing the negative effects of adapting from dissimilar sources. To evaluate our algorithms, we tested our algorithms on eight real smart home datasets.

1 Introduction

In the past decade various supervised methods have been proposed for activity recognition from sensor data [6, 12, 15]. A problem with supervised activity recognition methods is the need for labeled data, whereas labeling human activity from sensor data is very laborious, time consuming and error-prone. Unsupervised methods such as frequent pattern mining methods [5, 16, 20] are more autonomous and less invasive, however they require large amounts of data to be collected beforehand. Therefore, the deployment process will be delayed substantially, resulting in an impractical solution in real world.

To solve this problem, domain adaptation solutions can be adopted [3, 4, 13]. Domain adaptation essentially tries to use an algorithm that has been trained on one or several source domains and adapts it to a target domain. Therefore, it is possible to skip the labeling process in a new environment and only collect a small amount of unlabeled data. A number of methods have been proposed for single source domain adaptation in smart homes. These methods include adapting learned activities for different residents [17], mapping different types of activities to each other [21], and adapting activities performed in two different spaces [7]. Recently Rashidi et al. [18] proposed a method for transferring activity knowledge from multiple spaces. They show how using multiple source domains improves the generalization capability of the algorithm and increases the chance that an activity is correctly recognized. They assume that all the sources are

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equally similar. In reality, this assumption can be violated, as some spaces might show a higher degree of similarity and therefore might be more suitable for domain adaptation, while some other spaces can be quite dissimilar.

Here, we explore a method of measuring the distance between a source and a target environment, called $\mathcal{H}$ distance. Using such a measure, we propose a method for selecting the most promising sources from a collection of available sources. This allows us to avoid the negative transfer effect [19]. Negative transfer effect refers to a case where adapting from a source domain might indeed result in performance degradation. It happens if the source and target domains not very similar. To the best of our knowledge, this is the first work addressing activity recognition as a multi source domain selection and adaptation problem by measuring the distance between activities performed in different environments.

2 Proposed Model

Our input data is a sequence of sensor events. Each sensor event has a timestamp and is associated with a sensor ID. In case of annotated data, each sensor event is also associated with an activity label l such as "cooking". The source domains are those smart homes in which we previously have collected data and annotated it. The target domain is a new smart home in which we intend to deploy an activity recognition system, and in which we only have collected a few days worth of unlabeled data. Note that it is possible that a hypothesis from a particular source domain might not work well on the target domain, causing the negative transfer effect. Our objective is to appropriately combine hypotheses from source domains to infer the label of activities in the target domain.

To do this, we calculate the pairwise similarity between each source and target using $\mathcal{H}$ distance [8]. It computes the distribution difference based on finite samples of data. We select the most promising sources based on the average similarity and combine them in a weighted manner.

2.1 Measuring Domain Distance

In order to be able to select the most promising domains among a list of available domains, we need to quantify the difference between the source and target environments. Selecting the most promising sources instead of using all the sources in a brute force manner allows us to avoid the negative transfer effect.

There are a number of measures for computing the distance between two distributions, such as JSD divergence [10] and KL divergence [9]. Both require distribution estimation, where in a distribution-free setting such as in our scenario, accurate estimates cannot be obtained from finite samples. Other distance measures such as L^1 or L^p norms are either too sensitive or too insensitive [8].

We use a classifier induced divergence measure called $\mathcal{H}$ distance [8] which measures the divergence only affecting the classification accuracy. Unlike other distribution distance measures such as JSD or KL divergence, it's possible to compute it from finite unlabeled samples of two distributions. More importantly, one can use the well known machine learning classification methods to estimate the distance. Blitzer et al. [3] used a variant of $\mathcal{H}$ distance as a criterion for adaptability between unlabeled domains. Here, we use it as a distance measure in order to combine hypotheses from various domains, and to discard less promising sources to avoid the negative transfer effect.

Let $\mathcal{A}$ be a family of subsets of $\Re^k$ corresponding to the characteristic functions of classifiers. Then the $\mathcal{H}$ distance between two probability distributions $\mathcal{D}$ and $\acute{\mathcal{D}}$ is defined as in Equation 1. Here sup refers to supremum.

$$d_{\mathcal{H}}(\mathcal{D}, \acute{\mathcal{D}}) = 2 * \sup_{A \in \mathcal{A}} |Pr_{\mathcal{D}}(A) - Pr_{\acute{\mathcal{D}}}(A)| \tag{1}$$

It can be shown that computing $\mathcal{H}$ distance for a finite sample is exactly the problem of minimizing the empirical risk of a classifier discriminating between instances drawn from $\mathcal{D}$ and $\acute{\mathcal{D}}$ [2]. In other words, we should label all the data points in the source domain as 0, and all the data points in the target domain as 1, regardless of their actual class labels. Then we can train a classifier to discriminate between the two domains, separating data points with a label of 0 from those data points with a label of 1. The more similar are the data points in the source and target domains, the more difficult it would be to separate the source and target data points, and therefore the higher would be the empirical risk. We re-write Equation 1 as Equation 2. Here ϵ_h is the empirical error when discriminating between source domain $\mathcal{D}_s$ and target domain $\mathcal{D}_t$ based on some hypothesis $h \in \mathcal{H}_s$, and $\mathcal{H}_s$ is the hypothesis space of source domain.

$$d_{\mathcal{H}}(\mathcal{D}_s, \mathcal{D}_t) = 2 * (1 - \arg \min_{h_j \in \mathcal{H}_s} (\epsilon_{h_j})) \tag{2}$$

We compute such a distance measure for each pair of source and target domains, and for each activity. This allows us to obtain a clear picture of domain similarity based on various activities.

2.2 Model Details

In order to facilitate domain adaptation, we have to transform the original raw features into new features. The sensor IDs are unique to each specific environment and might carry different meanings in each environment. For example, id_1 in one home might refer to an infrared motion sensor in the bedroom for detecting sleep activity. The same sensor ID id_1 in another home might refer to a cabinet sensor in the kitchen. We use the simple mapping $\mathcal{S} \to L(\mathcal{S})$ where $\mathcal{S}$ refers to the set of sensor IDs, and L refers to the location where a sensor is located (e.g. Bedroom). We maintain a unified list of locations across different environments. We use an N-gram model to represent the sequential nature of data [11]. An N-gram model for our sensor data shows the currently activated sensor, in addition to $N-1$ previously activated sensors, providing history context. We also use the start time of the activations to provide temporal context.

The source domains $\mathcal{D}_1$ through $\mathcal{D}_m$ provide us with m hypotheses h_1 .. h_m. First we select $n \leq m$ hypotheses based on the overall similarity between our target and each one of the sources. We then combine n hypotheses to infer a hypothesis h_t for the target domain. To combine hypotheses h_1 .. h_n, we weight the hypotheses by their corresponding pairwise activity similarities with the target domain, multiplied by the hypothesis confidence. Here we take the smoothness assumption [1], which states that two nearby (similar) patterns in a high density area (high confidence) should share similar decision values. Therefore we can assign a certain label to a particular activity in the target domain if the two domains are similar in terms of that particular activity, and also if our confidence is high about the predicted label of that activity. We assume that the target function h_t shares values with similar domains.

In order to use $\mathcal{H}$ distance in our activity recognition system, we need to adapt it to our scenario. Not only is it important to measure the overall similarity between source and target environments, but also it is important to know how many similar activities exist and what is their individual similarity value. We denote the distance between two domains $\mathcal{D}_s$ and $\mathcal{D}_t$ based on activity y as $d^y_{\mathcal{H}}(\mathcal{D}_s, \mathcal{D}_t)$. It is similar to computing the generic H distance, with the exception all the data points with a label other than y will be ignored during calculation. Note that such a distance measure is not symmetric. Consequently the activity based similarity measure is defined as in Equation 3.

$$\Phi^y(s,t) = 1 - d^y_{\mathcal{H}}(\mathcal{D}_s, \mathcal{D}_t) \tag{3}$$

To determine similarity between a source and target domain based on individual activities, we need to identify the target activities. As we assume that the target data is unlabeled, we have no way of telling which activity a certain sensor event belongs to. To solve this problem, we utilize a two-stage algorithm. First, we build an ensemble classifier using source datasets to assign a label to the target data points. Next, we will compute the individual activity based source-target similarity, and will select the promising sources. Then we will adjust the target points labels according to the source-target activity similarity. After finding the individual activity similarities $\Phi^y(s,t)$, the overall similarity between a source and target is defined as the average similarity over all activities.

In the next step, we select the most promising sources. To select the top n sources, given n, we choose n sources with the highest similarity value $\Phi(s,t)$. If n is not given, then we need to find a suitable value for n. To select the most promising sources, we consider the overall source-target similarity $\Phi(s,t)$, in addition to the total number of selected sources. This is reflected in Equation 4. The sources with Ψ above a threshold θ_Ψ will be selected.

$$\Psi(s_i) = \frac{\Phi(\mathcal{D}_{s_i}, \mathcal{D}_t)}{\sum_{s=1}^{m} \Phi(\mathcal{D}_s, \mathcal{D}_t)} * \sqrt{1 - \frac{n}{m}} \tag{4}$$

The first term in Equation 4 limits our choice of source domains to those with a similarity Φ above the average similarity. The second terms imposes a restriction on the number of selected source domains. This allows for a more efficient method, while achieving the desired accuracy.

Next, we combine the hypotheses from n selected sources. We assume that the confidence of a classifier i for a predicted label y is given by $h_i(y|x)$. Therefore, we can write the hypothesis combination rule as in Equation 5.

$$h_t(x) = \sum_{i=1}^{n} \arg\max_{y} h_i(y|x) * \Phi^y(s_i, t) \tag{5}$$

3 Experiments

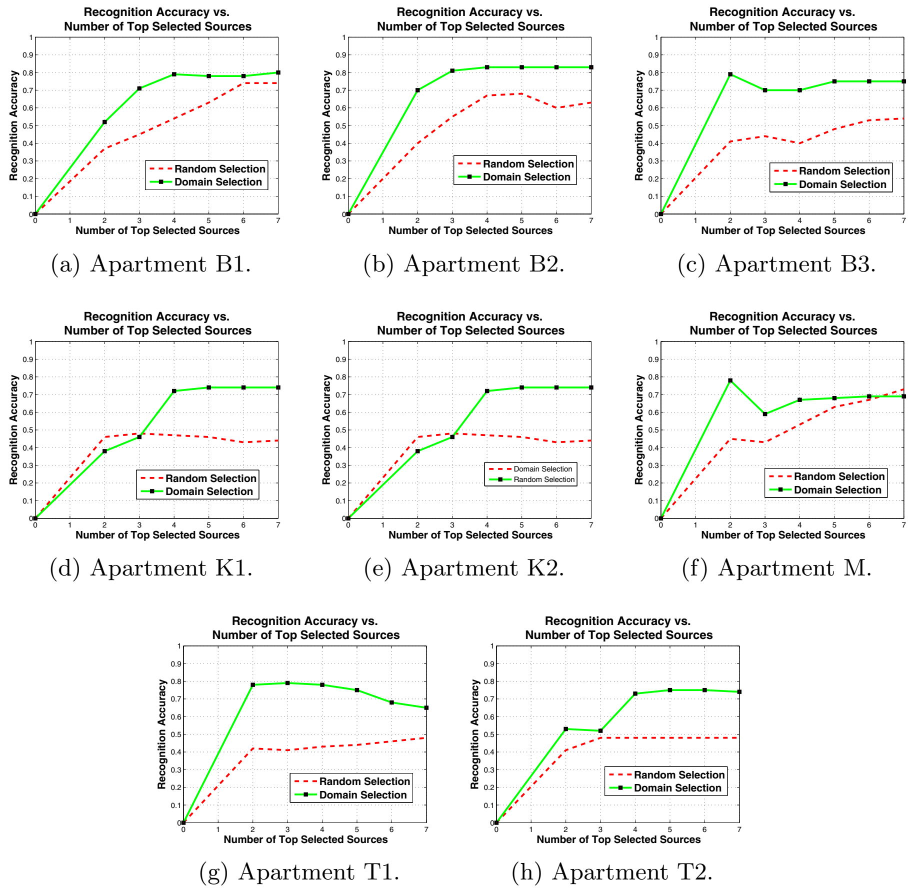
We tested our algorithms on 8 datasets collected from 6 smart homes. We refer to those 8 datasets as B1, B2, B3, K1, K2, M, T1 and T2. Apartments B1, B2, B3 were located in the same building complex. Datasets K1, K2 were collected from the same apartment, but within different time periods, housing different pairs of residents, and were annotated with different activities. The same is true for T1 and T2. All datasets are collected during a normal day to day life of residents. The list of locations included bathroom, shower, bedroom, kitchen, living room, work area, med cabinet, and entrance. A more detailed description of datasets can be found in Table 1. The sensors in our smart homes consist of infrared motion sensors, oven sensors, switch contacts on doors and cabinets, and light sensors.

Table 1. Characteristics of each dataset

Dataset	B1	B2	B3	K1	K2	M	T1	T2
Residents	1	1	1	2	3	1+ pet	2	2
Rooms	1	1	2	3	3	3	2	2
Sensors	32	32	32	71	72	32	20	20
Activity Instances	5714	4320	3361	497	844	1513	1431	166
Collection Days	126	234	177	61	38	88	120	10
Absent Activities	W	W	–	L,R,T,E,BT	T	T,B,E	H,T,S,B,BT,W	T

To evaluate the results of our algorithms based on a ground truth, we annotated the datasets with 10 activities of interest, including hygiene(H), leaving home(L), cooking(C), relaxing(R), taking medications(T), eating(E), sleeping(S), bathing(B), bed to toilet transition(BT) and working(W). For brevity we will refer to those activities using their abbreviated form (e.g. hygiene as H). As one would expect in a real world setting, not all activities are common between different homes, nor their distributions are the same.

To test our algorithm, we considered 8 different problem settings. In each setting, 7 datasets were considered as source, and the remaining dataset as target. The base classifier is a kernel based naive Bayes classifier with a Gaussian kernel [14]. After running our algorithm in a 10 fold cross validation manner, we found the midpoint threshold $\theta_{\Psi} = 0.5$ to be a suitable value for our experiments. The



(a) Apartment B1. (b) Apartment B2. (c) Apartment B3.

(d) Apartment K1. (e) Apartment K2. (f) Apartment M.

(g) Apartment T1. (h) Apartment T2.

Fig. 1. Activity recognition accuracies based on using different number of source domains

cross validation results also found the 3-Gram model to best represent the data, as higher gram values did not significantly change our results. The target and sample source datasets included 3 days of unlabeled data.

Figure 1 shows the overall activity recognition rates based on choosing the top n sources. We also performed experiments based on randomly selecting the top n sources (averaged over 10 runs), using a simple linear combination rule (no weights). One can clearly see that our domain selection algorithm outperforms random selection. It should be noted that our algorithm are based on using only a small sample of source and target datasets and it is possible that the chosen samples are not representative of the entire dataset, leading to lower recognition rates in some cases. Still, despite the fact that we are relying only on a small unlabeled target dataset, and despite the fact that the apartment layouts, sensors and residents are different, we were still able to achieve very reasonable recognition rates. In Figure 1 one can also see the effect of negative transfer. We can

Table 2. Comparison of pure supervised method and our method

Dataset	B1	B2	B3	K1	K2	M	T1	T2	Avg.
Recognition rate: supervised.	0.86	0.86	0.9	0.63	0.79	0.73	0.88	0.76	0.80
Recognition rate: our method	0.79	0.83	0.75	0.69	0.74	0.68	0.78	0.73	0.75

see that adding more data sources does not necessarily increase the recognition accuracy in the target environment. We used our source selection algorithm for choosing the best number of sources. Using our method, 95% of the maximum achievable accuracy was achieved using only 4.5 sources in average. The average accuracy was 74.88%. This shows how our algorithm can approximate the best number of promising sources, balancing efficiency and accuracy.

The detailed accuracies based on choosing the best number of sources are shown in Table 2. Table 2 shows accuracy results for a similar supervised method that uses all of the "labeled" target dataset for training. In contrast our method uses about 8.7% of the target dataset in average. It can be seen that though our method uses only a small fraction of "unlabeled" target dataset, it surprisingly works well. In some cases such as for the K1 dataset our algorithm even outperforms the supervised method. These experiments show how our method can be useful in a real world situation where supervised methods are expensive and impractical due to the time constraints and annotation costs.

4 Conclusions and Future Work

By selecting the best source domains, we showed that it is possible to recognize activities in a target environment despite using only limited unlabeled target data, and despite the fact that the residents, the number of activities, the sensor layouts and the building floorplans can be different in source and target environments. In the future, we intend to combine this method with active learning methods in order to boost our bootstrap method.

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Daily Human Activity Recognition Using Depth Silhouettes and $\Re$ Transformation for Smart Home

Ahmad Jalal[1], Md. Zia Uddin[2], Jeong Tai Kim[3], and Tae-Seong Kim[1]

[1] Department of Biomedical Engineering, Kyung Hee University,
1 Seochun-ri, Kiheung-eup, Yongin-si, Kyunggi-do, 446-701, Republic of Korea
[2] Department of Electronic Engineering, Inha University,
253 Yonghyun-dong, Nam-gu, Incheon, 402-751, Republic of Korea
[3] Department of Architectural Engineering, Kyung Hee University,
1 Seochun-ri, Kiheung-eup, Yongin-si, Kyunggi-do, 446-701, Republic of Korea
jalalahmad25@yahoo.com, ziauddin@inha.ac.kr,
{jtkim,tskim}@khu.ac.kr

Abstract. We present a human activity recognition (HAR) system for smart homes utilizing depth silhouettes and $\Re$ transformation. Previously, $\Re$ transformation has been applied only on binary silhouettes which provide only the shape information of human activities. In this work, we utilize $\Re$ transformation on depth silhouettes such that the depth information of human body parts can be used in HAR in addition to the shape information. In $\Re$ transformation, 2D directional projection maps are computed through Radon transform, and then 1D feature profiles, that are translation and scaling invariant, are computed through $\Re$ transform. Then, we apply Principle Component Analysis and Linear Discriminant Analysis to extract prominent activity features. Finally, Hidden Markov Models are used to train and recognize daily home activities. Our results show the mean recognition rate of 96.55% over ten typical home activities whereas the same system utilizing binary silhouettes achieves only 85.75%. Our system should be useful as a smart HAR system for smart homes.

Keywords: Human activity recognition, Depth silhouettes, $\Re$ transformation, Smart home.

1 Introduction

Human activity recognition (HAR) has become one of the challenging and active areas of research recently with its essential role for smart homes. General approach of video-based HAR is to extract some significant features from each video frame, and use these features to train a classifier and perform recognition [1]. A HAR system can keep a continuous observation on basic human activities of daily living, allowing various services such as lifecare from physical damage, nursing, rehabilitation, and health assistance to make a more intelligent home environment [1]. In recent years, HAR becomes a key component in a smart home system providing various applications such as home activity monitoring and e-healthcare [2]. Numerous smart home projects (e.g., Microsoft Easyliving project and House_n group at MIT) [1] are currently underway.

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In the video-based HAR, typically binary silhouettes [3] are used for human activity representation however they produce ambiguity among the same silhouette for different postures of different activities due to their limited pixel value (i.e., 0 or 1, thus within the binary shape of a posture, no information presents). To extract activity shape features, Principle Component Analysis (PCA) and Independent Component Analysis (ICA) have been used [2, 4], producing the spatial features that are global and local respectively. However these features are sensitive to translation and scaling of human body postures which are problems in the silhouette extraction process. To derive the translation and scaling invariant features (thus reducing the burden on the silhouette extraction process in our case), $\Re$ transformation has been proposed. $\Re$ transformation first computes a 2D angular projection map of an activity silhouette via Radon transform, then converts the 2D Radon transformed map into a 1D $\Re$ transform profile. $\Re$ transformation [5] was first introduced to classify objects from images and extract distinct directional features of each binary shape. In [6], Singh et al proposed Radon transform to identify the skeleton representation for the human recognition. In [7], Chen et al. implemented Radon transform for its sensitiveness to angle variation to promote gender recognition using binary silhouettes. In [3], $\Re$ transform was applied on binary silhouettes to describe the spatial information of different human activities. However the binary silhouettes cause limited recognition performance due to a lack of information in the flat pixel intensity, and difficulties to differentiate between the far and near distance of the human body parts. Recently to overcome the limitation of the binary silhouettes, depth based silhouette representation for human activity has been suggested [8-10], since depth silhouettes differentiate the body parts by means of different intensity values.

In this work, we propose a depth silhouette based home HAR system for smart homes. $\Re$ transformation is applied on the depth silhouettes. PCA is applied to extract features from the $\Re$ transformed profiles of depth silhouettes, and then Linear Discriminant analysis (LDA) is applied to make them more robust. Finally, the features are utilized in Hidden Markov Model (HMM) for recognition of ten daily home activities. Our results show that significant improvement over the systems where only the binary silhouette features are used in recognition. The proposed system could be an essential component of a smart home system for continuous observation of daily human activities.

2 Methodology

Our HAR system consists of depth silhouette extraction, feature representation and extraction (including $\Re$ transformation, PCA, and LDA), and modeling of HMMs (including codebook generation, training, and recognition). Fig. 1 shows the overall flow of our proposed human activity recognition system.

2.1 Depth Silhouette Preprocessing

To capture depth images of activities, we utilized a ZCAM^{TM} [11]. Activity silhouettes are extracted from depth images and resized to 50×50. Figs. 2 (a) and (b) show some sample of binary and depth silhouette sequential images of a rushing activity.

In Fig. 2, it is clear that binary silhouettes contain limited information due to its flat pixel intensity value (i.e., 0 or 1) distribution over the human body (i.e., only shape information is available) while depth silhouettes show discernable parts in addition to the shape information.

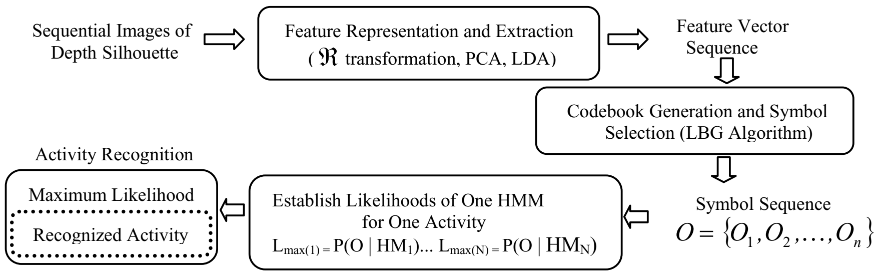


Fig. 1. Overall flow of our proposed human activity recognition system

Fig. 2. Two sequences of (a) binary and (b) depth silhouettes of a rushing activity

2.2 Feature Representation

To derive translation and scaling invariant features from the depth activity silhouettes, $\Re$ transformation including Radon transform is the key technique used in the proposed approach. First, Radon transform computes a 2D projection of a depth silhouette [6] along specified view directions. It is applied on each depth silhouette to establish a mapping between the domain produced by the image coordinate system $f(x,y)$ and the Radon domain indicated as $\Re(\rho, \theta)$.

Let $f(x,y)$ is the depth silhouette, its Radon transform $\Re(\rho,\theta)$ is computed by

$$\Re(\rho, \theta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y)\, \delta(x\cos\theta + y\sin\theta - \rho)\, dx\, dy \tag{1}$$

where δ is the Dirac delta, $\rho \in [-\infty, \infty]$ and $\theta \in [0, \pi]$.

Then $\Re$ transform [3, 5] is used to transform the 2D Radon projection to make a 1D $\Re$ transform profile for every frame.

$$\Re_T(\theta) = \int_{-\infty}^{\infty} \Re^2(\rho, \theta)\, d\rho \tag{2}$$

Basically, $\Re$ transform is the sum of the squared Radon transform values along the specified angle θ. It provides a highly compact shape representation and reflects the time-sequential profiles of each daily home human activity. In addition, these $\Re$ transform profiles are translation and scaling invariant. Fig. 3 shows the general flow of $\Re$ transformation using a set of depth (walking) activity silhouettes.

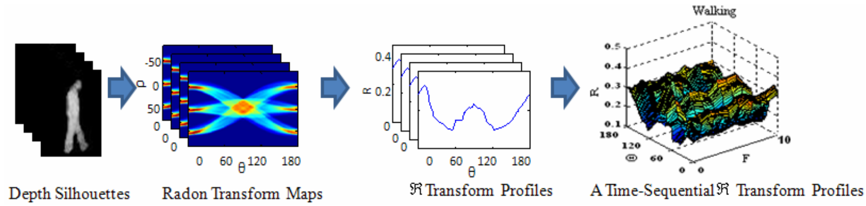


Fig. 3. Overall flow of Radon transform using depth silhouette activities

Fig. 4 shows the whole set of ℜ transform time-sequential profiles of all human home activities we recognize in this study: namely, cleaning (vacuuming), cooking, eating, exercise (dumb-bell), lying-down, rushing, sitting-down, standing-up, take-an-object, and walking. These 3D representations of time evolving ℜ transform profiles are derived from a video clip of ten consecutive frames F for each activity. It is shown that ℜ transform profiles show distinct characteristics of the ten home human activities.

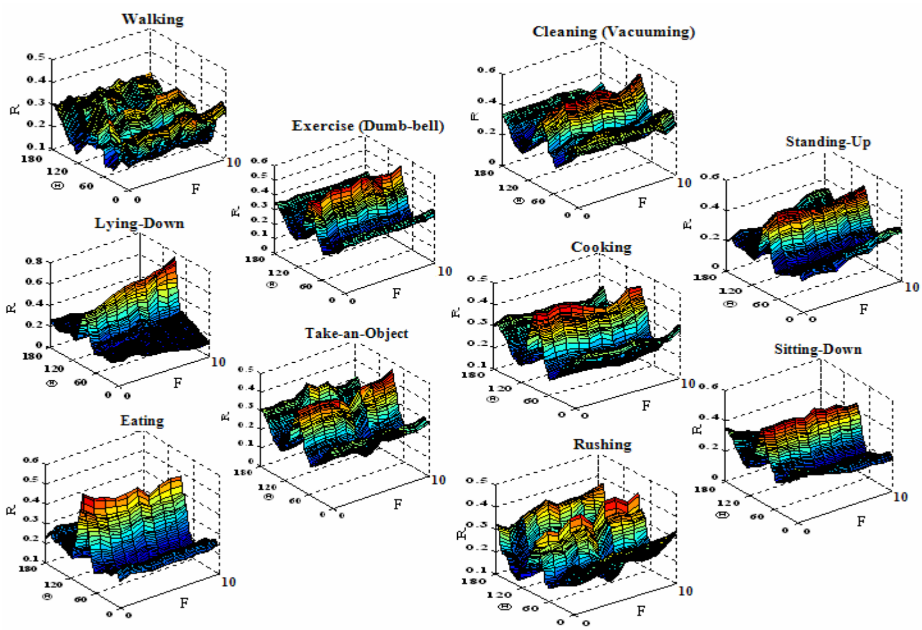
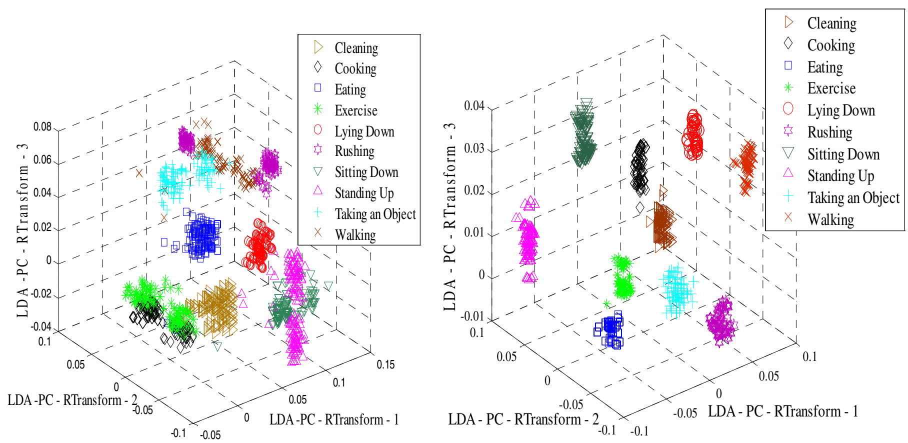


Fig. 4. Plots of time-sequential ℜ transform profiles from the depth silhouettes of our ten daily home human activities

2.3 PCA and LDA for Silhouette Feature Extraction

After computing the ℜ transformation profiles, PCA [4] is used to extract the dominant features. Thus the principal components (PCs) of the ℜ transformed profiles of

the depth silhouettes are expressed as $P_i = \overline{\overline{X}}_i V_e$, where P_i is the PCA projection on the $\Re$ transformed profiles, and $\overline{\overline{X}}_i$ is the zero mean vector of $\Re$ transformation profiles. V_e is the leading eigenvectors corresponding to the first top eigenvalues. Finally, LDA [12] finds a set of discriminant vectors F_{LDA} that maximizes the ratio of the determinant of the between S_B and within S_W class scatter matrix as $F_{LDA} = \left|F^T S_B F\right| / \left|F^T S_W F\right|$. Thus, the feature vectors using LDA on PC- $\Re$ features can be represented as $L_{PC\_RTrans} = \Re_T(\theta) P_i F_{LDA}$ respectively where L_{PC_RTrans} indicates the LDA on PC- $\Re$ features representation for the i^{th} depth silhouette image.
Figs. 5(a) and (b) show the 3D plots of the features after applying the proposed feature extraction methods on the binary and depth silhouettes of our home activities. In Fig. 5 (a), a pair of activities such as (cooking and exercise) and (walking and rushing) are very close to each other. While in Fig. 5 (b), all activities are well separated among each other.



(a) (b)

Fig. 5. Plot of the LDA on PC- $\Re$ features on (a) the 1,500 binary silhouettes, and (b) 1,500 depth silhouettes of our home activities

2.4 Activity Recognition via HMM

HMM is based on a number of finite states connected by transitions where every state contains transition probability to other state and symbol observation probability. In our study, for modeling, training, and recognizing the home activity, HMM [12] is used since it can deal with the sequential silhouette data with a probabilistic learning process. In a discrete HMM, the feature vectors should be symbolized. We used the Linde, Buzo, and Gray (LBG)'s clustering algorithm [14] to generate a codebook of vectors for HMM.

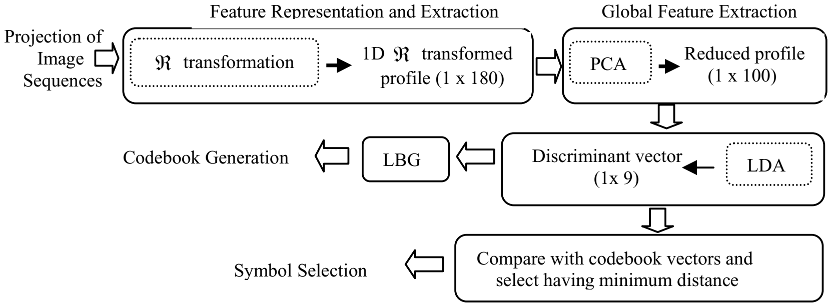


Fig. 6. Codebook generation and symbol selection

Fig. 6 shows the procedure of codebook generation and symbol selection on the LDA on PC features of the ℜ transformed silhouettes. Fig. 7 shows the structure and transition probabilities of a walking HMM before and after training with the codebook size of 32 [13].

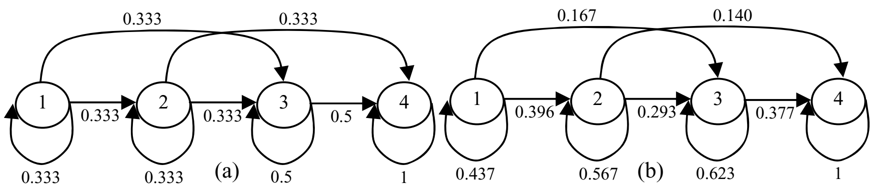


Fig. 7. Walking HMM structure and transition probabilities (a) before and (b) after training

3 Experimental Results

To test our system, we built our own depth silhouette database of the ten daily home activities and recorded multiple test sets from three different subjects. The collected video clips were split into several clips where each clip contained ten consecutive frames. A total of 15 clips from each activity were used to build the training feature space and the whole training data contained a total of 1,500 depth silhouettes. Initially, each depth silhouette vector with its size of $1 \times 2{,}500$ was transformed via ℜ transformation, producing a 1D profile of 1×180. Further reduction in dimension was performed by PCA producing the feature of 1×100, and finally LDA was performed ending up with a feature vector of 1×9. In our home activity model, we applied 15 video clips of each activity in training and 45 video clips in testing of depth silhouette images respectively. Table 1 shows the recognition results from the binary and depth activity silhouettes respectively utilizing two different features sets where the proposed LDA on PC-ℜ feature approach on the depth silhouette shows significantly superior mean recognition of 96.55% over that of the binary silhouettes (i.e., 85.75%).

Table 1. Recognition results of different feature extraction approaches using both binary silhouettes and depth silhouettes

Approaches	Home human Activities	Recognition Rate(Binary)	Recognition Rate (Depth)	Mean (Binary)	Mean (Depth)
PC-$\Re$ features	Cleaning	72.50%	87.50%	72.40%	88.65%
	Cooking	51.50	79.0		
	Eating-Drink	84.0	100		
	Exercise	57.50	84.50		
	Lying Down	100	100		
	Rushing	66.50	86.50		
	Sit Down	63.0	84.0		
	Stand Up	81.50	90.50		
	Take Object	72.0	83.50		
	Walking	75.50	91.0		
LDA on PC-$\Re$ features	Cleaning	85.50	94.50	85.75	96.55
	Cooking	75.50	91.0		
	Eating-Drink	97.50	100		
	Exercise	78.0	96.0		
	Lying Down	100	100		
	Rushing	82.0	96.0		
	Sit Down	80.50	95.50		
	Stand Up	88.50	92.50		
	Take Object	82.50	100		
	Walking	87.50	100		

4 Conclusions

We have presented a depth silhouette and $\Re$ transformation based HAR system for smart homes. In our results, the use of depth silhouettes and $\Re$ transformation improves the recognition rate up to 96.55% over the conventional systems where the PC-$\Re$ features and LDA on PC-$\Re$ features based on the binary silhouettes achieved only 72.40% and 85.75% respectively. The proposed system can be implemented at smart home to recognize daily activities of residents.

Acknowledgement

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Activity Recognition in Smart Environments: An Information Retrieval Problem

Belkacem Chikhaoui[1], Shengrui Wang[1], and Hélène Pigot[2]

[1] Prospectus Laboratory, University of Sherbrooke, Canada
[2] Domus Laboratory, University of Sherbrooke, Canada
{belkacem.chikhaoui,shengrui.wang,helene.pigot}@usherbrooke.ca

Abstract. Activity recognition in smart environments and healthcare systems is gaining increasing interest. Several approaches are proposed to recognize activities namely intrusive and non-intrusive approaches. This paper presents a new fully non-intrusive approach for recognition of Activities of Daily Living (ADLs) in smart environments. Our approach treats the activity recognition process as an information retrieval problem in which ADLs are represented as hierarchical models, and patterns associated to these ADLs models are generated. A search process for these patterns is applied on the sequences of activities recorded when users perform their daily activities. We show through experiments on real datasets recorded in real smart home how our approach accurately recognizes activities.

1 Introduction

The recent emergence of ubiquitous environments, such as smart homes, has enabled the housekeeping, assistance and monitoring of chronically ill patients, persons with special needs or elderly in their own home environments in order to foster their autonomy in the daily living life by providing the required service when and where needed [5,1]. By using such technology, we can reduce considerably costs, and alleviate healthcare systems. However, many issues related to this technology were raised such as activity recognition, person identification, assistance and monitoring.

Activity recognition in smart environments is gaining increasing interest among researchers in ubiquitous computing and healthcare. Automatic recognition of activities is an important and challenging task. One of the typical applications in healthcare systems is the assistance and monitoring of the Activities of Daily Living (ADLs) for persons with special needs and elderly to provide them with the appropriate services [3].

Several research works have been done, and several models have been proposed to recognize activities using intrusive and non-intrusive approaches. Activity recognition using intrusive approaches requires the use of specific equipments such as cameras. However, these approaches are opposed to ethical aspects, and do not preserve the privacy of persons. Activity recognition using non-intrusive approaches is a complex task, and it is based on a deep analysis of the data

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gathered from the environment [8,2,10,11,4,7]. The sensors disseminated in the environment sense events about the state of the environment and any changes that happen within it. Each sequence of events is associated to a particular activity. To each activity is associated a set of patterns. In fact, by discovering these patterns, the underlying association rules, temporal constraints and progress and changes over time, it becomes possible to characterize the behavior of persons and objects and automate tasks such as service adaptation, activity monitoring and assistance [9].

In this paper, we propose a new approach to recognize ADLs in smart environments. In our approach, the activity recognition process is treated as an information retrieval problem. To this end, a search process is applied on the sequences of activities recorded from the smart environment, in order to find the patterns generated from activity models. In our approach, activities are represented as hierarchical models [6].

Our work makes several contributions. First, our approach recognizes activities without any prior data annotation, which is an important issue resolved in our work. Second, our approach is validated using real data gathered from a real smart home which makes our results more confident and our experiments repeatable. Third, our approach deals with the problem of scalability by taking into account the sequences recorded independently of the environment. Finally, our approach is generic and can be applied to any sequential datasets.

The rest of this paper is organized as follows. Section 2 presents our approach namely the activity models and how patterns are generated. In section 3, we demonstrate the potential and suitability of our approach through an experimental study, followed by the experimental results in section 4. Finally, we conclude the paper in section 5.

2 Proposed Approach

In this section we present our approach for ADLs recognition. We first introduce the activity models, after that we present our proposed algorithm.

2.1 Activity Model

According to one human behavior theory, humans perform activities in a hierarchically structured manner to accomplish their goals [6]. Based on this principle, we adopt a hierarchical representation of activities as shown in Figure 1. Thus, activities might be decomposed into tasks and subtasks, until reaching terminal tasks (elementary tasks) which can not be decomposed. Complex activities are recognized in a bottom-up way by identifying terminal tasks, subtasks, tasks, and activities which constitute the root of the hierarchy. In a sequential activity, if the task T_1 should be executed before the task T_2, thus, all the subtasks of T_1 should be executed before those of T_2, which is not the case for concurrent activities where the order of performing some tasks is not important.

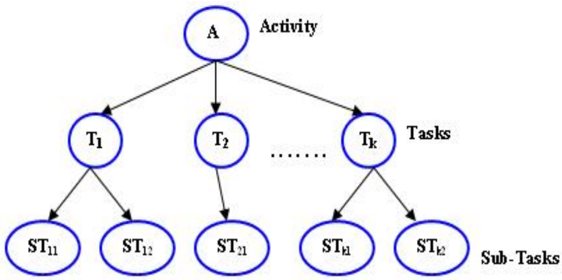


Fig. 1. Hierarchical activity model

Given that objects in the Domus smart home[1] are not tagged using RFID sensing, recognizing objects involved in activities is a real and challenging problem. To deal with this problem, objects are ranged in well defined locations such as lockers. The states of the electromagnetic sensors indicate whether objects stored in lockers are taken or not for a specified activity. For example, the "teapot" used in the preparing tea activity of series 2 in our experiments (see section Experiments) is usually placed in the locker $B8$ in the kitchen, when this locker is opened we deduce that the teapot is used in the activity to which it is associated. Therefore, objects are associated to sensors that indicate their use in activities. This process is done manually, but does not constitute a major constraint in our approach given that this process is applied only for important objects in the activity. Table 1 shows some activities with related objects.

Table 1. Some ADLs with some related objects

Activity	**Related objects**
Wake Up	bed, bedroom light switch, door contact
Toileting	door contact, toilet flush, faucet
Preparing breakfast	fridge, cups, spoons, toaster
Preparing tea	tea, teapot, cups, oven, faucet

For each activity model, we generate patterns using sensors associated to objects. For example, (bed sensor, bedroom light switch sensor, and door sensor) related to the "Wake up" activity. Patterns are generated by taking into account the different possible scenarios of doing the activity. For instance, we analyze the activity "Wake up" which is a simple ADL with low complexity, that will be held in the bedroom zone. Let assume that the bedroom zone (example of the Domus smart home) includes the following sensors: Lamp Light switch and Door contact, with two states respectively for each sensor (OPEN, CLOSE). To represent this activity, the following patterns of length $N = 3$ for example could be generated: (Lamp Bedroom close, Lamp Bedroom open, Door Bedroom close),

[1] domus.usherbrooke.ca

(Lamp Bedroom close, Lamp Bedroom open, Door Bedroom open), (Lamp Bedroom open, Lamp Bedroom close, Door Bedroom open), (Lamp Bedroom open, Door Bedroom open, Door Bedroom close), (Lamp Bedroom open, Door Bedroom open, Lamp Bedroom close), ..., etc. Given the variability in the human behavior, multiple patterns might be generated. However, with a learning system that learns the human behavior, patterns might be reduced to only the most interesting ones that characterize the human behavior.
We define a score measure SM that represents the percentage of patterns found in the sequence dataset $\mathcal{D}$. The score measure is computed as follows:

$$SM = \frac{|FP|}{|M_i|} \tag{1}$$

where FP represents the number of patterns found in $\mathcal{D}$, and $|M_i|$ represents the number of patterns generated for the activity model M_i. The higher SM value is, the higher recognition accuracy will be. If SM is smaller than a certain specified threshold, then the activity is not recognized and will be considered as "Unknown" activity.

2.2 Algorithm

After introducing the activity models, the different steps involved to recognize activities are summarized below. The algorithm takes as input the sequence dataset $\mathcal{D}$ that contains all the event sequences, the length N of the patterns to be extracted, and the set of activities models $\mathcal{M}$. The output of the algorithm is the set of recognized activities.

1. **Step 1**: Generate patterns of length N for each activity model.
2. **Step 2**: Search in the sequence dataset $\mathcal{D}$ for the set of patterns of each activity model.
3. **Step 3**: Compute the score measure for each activity model.
4. **Step 4**: Return recognized activities.

3 Experiments

In this section, we present the datasets obtained from experiments conducted at the Domus smart home to validate our approach. The Domus smart home, is a one bedroom apartment mounted inside the University of Sherbrooke. It includes one bedroom, one bathroom, a kitchen, a dining room, and a living room. The Domus smart home is equipped with different types of sensors such as infra red sensors, electromagnetic sensors, pressure detector, switch contacts, door and closet contacts, and flow sensors that provide the taps and the flush toilet states. During these experiments, six adults have participated to these experiments. In these experiments, we evaluated the early morning routines (wake up, toileting, preparing and having breakfast), which correspond to the basic everyday tasks of life. The experiments were held in the Domus smart home apartment in 2 times.

In the first experiments (Series 1), the user was asked to perform the early morning routine as he is supposed to do at home. In the second time (series 2) he was asked to repeat the same routine where a constraint was introduced during the experiment. This constraint consists in learning a tea recipe which lasts at most 10 minutes. In series 1 the user came 10 times to the laboratory during two consecutive weeks. After 2 weeks break, the user was asked to come for 5 days on one week to perform the series 2. In both series, the user can use any equipment available in the apartment, and decides the order of the activities that composed his routine. Each experiment lasted about 45 minutes. The dataset is composed of 59 sequences (corresponding to series 1, one sequence was damaged, so discarded from experiments), and 30 sequences (corresponding to series 2). The length of sequences varies between 100 and 470 events (series 1), and between 210 and 680 events (series 2). The number of sensors installed in the Domus smart home apartment is 36, which leads to 72 sensors states (ON, OFF, OPEN, CLOSE, ..., etc), in addition to one sensor (pressure detector) with one state, for a total of 73 sensors states.

4 Experimental Results

In this section we present the experimental results obtained using our approach. A total of five models of activities are built using the method described in the activity model section. Four models are used to recognize activities in the dataset of series 1, and five models are used to recognize activities in the dataset of series 2. The five models correspond respectively to the activities “Wake up”, “Toileting”, “Preparing Breakfast”, “Having Breakfast”, and “Preparing Tea”. The results are obtained using two different values of the patterns length $N = 2$ and $N = 3$. Tables 2 and 3 show the results of the activity recognition accuracy using respectively a pattern length $N = 2$ and $N = 3$ for the series 1.

Table 2. Recognition accuracy using a pattern length $N = 2$

Activity	Number of instances	Recognition	Recognition accuracy (%)
Wake Up	49	48	97.95
Toileting	49	49	100
Preparing breakfast	59	58	98.3
Having breakfast	59	43	72.88
Average accuracy			**92.28**

In the series 2 dataset, another activity is introduced which is preparing the tea recipe, this make a total of five activities to be recognized. Tables 4 and 5 show the results of the activity recognition accuracy using respectively a patterns length $N = 2$ and $N = 3$.

The results obtained are graphically represented in Figures 2(a) and 2(b).

The activity recognition results of the overall activities demonstrate the effectiveness and suitability of our approach. The lowest recognition accuracy in series 1 is observed in the activity “Having Breakfast” with an accuracy of (62.71

Table 3. Recognition accuracy using a pattern length $N = 3$

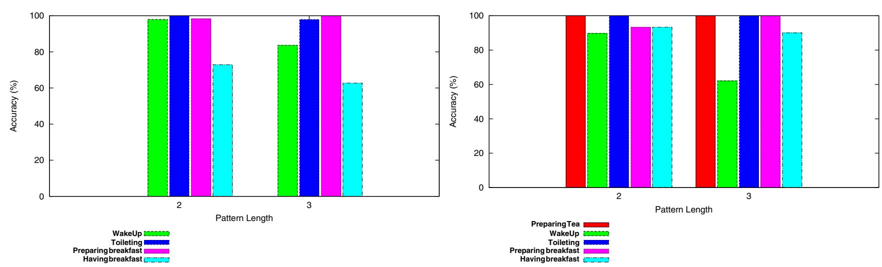
Activity	Number of instances	Recognition	Recognition accuracy (%)
Wake Up	49	41	83.67
Toileting	49	48	97.95
Preparing breakfast	59	59	100
Having breakfast	59	37	62.71
Average accuracy			**86.08**

Table 4. Recognition accuracy using a pattern length $N = 2$

Activity	Number of instances	Recognition	Recognition accuracy (%)
Wake Up	29	26	89.65
Toileting	24	24	100
Preparing breakfast	30	28	93.33
Having breakfast	30	28	93.33
Preparing tea	30	30	100
Average accuracy			**95.26**

Table 5. Recognition accuracy using a pattern length $N = 3$

Activity	Number of instances	Recognition	Recognition accuracy (%)
Wake Up	29	18	62.06
Toileting	24	24	100
Preparing breakfast	30	30	100
Having breakfast	30	27	90
Preparing tea	30	30	100
Average accuracy			**90.41**



(a) Series 1 (b) Series 2

Fig. 2. Recognition accuracy in our approach

%) as shown in Table 3. In series 2, the lowest recognition accuracy is observed in the activity "Wake up" with an accuracy of (62.06 %) as shown in Table 5. The reason why the activities "Wake up" and "Having Breakfast" present the lowest recognition accuracy is that these activities take place in two zones (Bedroom and Diningroom respectively) with a small number of sensors. The small number of sensors leads to the generation of a few number of patterns of great size. Indeed, the lowest recognition accuracies in both series 1 and 2 are observed using patterns of length $N = 3$ as shown in Tables 3 and 5. However, the recognition accuracy is increased using patterns of length $N = 2$ as shown in tables 2 and 4. However, patterns of greater size might be a promising solution where the zone includes a great number of sensors. The overall best results of activity recognition in series 1 and 2 (92,28 % and 95.26 %) are obtained using patterns of length $N = 2$. Activities not recognized are regarded to as unknown activities.

4.1 Scalability

To test the scalability of our algorithm with respect to the number of sequences, we used the series 2 dataset with four activities : “Wake up”, “Toileting”, “Preparing Breakfast”, and “Having Breakfast” using a pattern length $N = 2$. Figure 3 shows that our activity recognition algorithm has a linear scalability

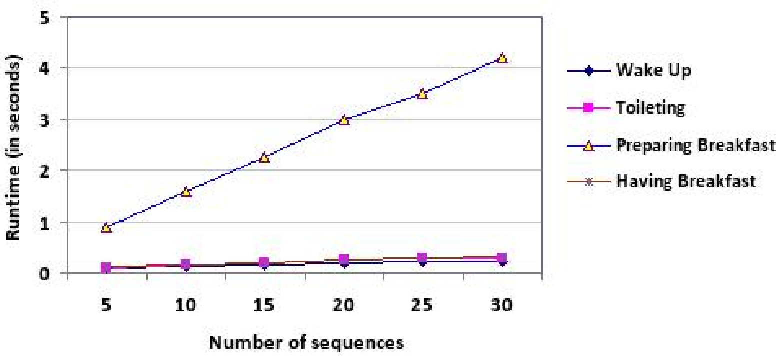


Fig. 3. Scalability evaluation

in terms of running time versus the number of sequences in the dataset, varying from 5 to 30 sequences in series 2. Our algorithm scales much better with the activities “Wake up”, “Toileting”, and “Having Breakfast”. This argues that our approach is suited for enabling scalability to long-term activities recordings.

5 Conclusion and Perspectives

In this paper we introduced a new approach to recognize daily living activities. Based on the activity models, patterns are generated for each activity model, then a search process is applied to find the generated patterns in the sequence datasets. The recognition accuracy is determined by a score measure computed by dividing the number of patterns found in the sequence datasets by the number of patterns generated for each activity model. We conducted an evaluation of the performance of our approach on 5 activities performed by 6 users. The experimental results showed that our approach achieves high accuracy without

having to rely on the data annotation required in the overall existing approaches. Despite the few datasets used in our experiments (89 sequences, recorded in 45 minutes per sequence, for a total of 4005 minutes of recording) and the small number of ADLs used in this work, we demonstrated the effectiveness and suitability of our approach in recognizing activities, and dealing with the problems of data annotation and scalability, by taking advantage of the patterns discovery principle. In addition, our proposed approach is suitable for distinguishing between people performing activities and characterizing their behaviors. This work will be explored in future extension of our approach.
In the future, we plan to extend our approach for online activity recognition by using a sliding time window over event sequences, this will allow also to perform an online person tracking in the environment. Moreover, our approach recognizes simple ADLs, we intend to extend our approach for recognizing more complex activities such as concurrent and interleaved activities.

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Annotating Sensor Data to Identify Activities of Daily Living

Mark Donnelly[1], Tommaso Magherini[1], Chris Nugent[1], Federico Cruciani[2], and Cristiano Paggetti[2]

[1] Computer Science Research Institute, University of Ulster, Shore Road, Newtownabbey, BT37 0QB, Northern Ireland
{mp.donnelly,cd.nugent,t.magherini}@ulster.ac.uk
[2] I+ s.r.l., 50144 Florence, Italy
{f.cruciani,c.paggetti}@i-piu.it

Abstract. DANTE is an application, which supports the annotation of ADLs captured using a pair of stereo cameras. DANTE is able to interpret the position and orientation of any object that is tagged with a special marker. Offline, users navigate frame-by-frame through captured scenes to annotate onset/completion of object interactions. The main utility is supporting the development of large annotated datasets, which is essential for the development and evaluation of context-aware models to interpret and monitor occupant behaviour within smart environments. DANTE only records scenes during which 'tagged' objects are interacted with therefore significantly reducing the amount of redundant footage recorded. The current study has extended the concepts of DANTE and has used it to support the annotation of additional sensor platforms. Results demonstrated both the capability of DANTE to support annotation of other platforms along with reducing the amount of time previously required to manually annotate such data by more than 45%.

Keywords: Data Acquisition, Multi sensor systems, Video Recording, Optical Tracking, Data Annotation.

1 Introduction

It is a well-recognised fact that the generation of large annotated data sets is a core research priority within the smart homes research domain. Only by referring to a large source of validated data can we begin to fully understand activities of daily living (ADL) patterns and develop intelligent context-aware algorithms, which will be robust when deployed *in situ* [1-3]. To date, several annotated open source datasets have been produced and shared with the research community [4-6], however, a challenge still remains in providing sufficiently large datasets with a completely accurate gold standard [2, 3]. The process of annotation is largely a manual cumbersome task. Typically, occupants keep hand-written diaries to record the details of every activity performed within a home environment, which are then compared with sampled sensor data to identify and label identified ADLs [7, 8]. Not surprisingly, this process is prone to high levels of error due to missing diary entries or incorrect time information.

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In the current paper, we describe the use of a video-based annotation tool referred to as DANTE (Dynamic ANotation Tool for smart Environments) to support the annotation of two additional sensor platforms. DANTE removes the need to involve occupants during the data collection phase and reduces the requirement for manual annotation of the data post experimentation. The remainder of the paper is structured as follows: in Section 2, we briefly describe related work in this domain; Section 3 outlines the DANTE system and describes its functionality; Section 4 presents and discusses the experiments, which have been performed to evaluate the proposed approach; and finally, Section 5 provides concluding statements, which summarise the findings.

2 Related Research

Coyle *et al.* [3] attempted to alleviate the issues with manually annotating sensor data by incorporating video into the recording process within a smart office environment. Coupled with written diaries, cameras were used to validate a number of activities. Coupled with this, pressure sensors where used to infer important periods (e.g. person entering a room) where the captured video data would likely contain activity related information. The investigators reported that this process significantly reduced that amount of video data, which had to be reviewed post recording.

Cook *et al.* presented a comprehensive overview of four annotation methods in [2]. The methods included: annotation of raw sensor data; annotation of raw sensor data coupled with resident diaries; using a 3D environmental visualisation tool; and the latter coupled with resident diaries. They employed Bayesian classifiers to evaluate the labeled data and reported that the visualisation tool, coupled with resident diaries provided the most rapid platform for annotating data and was the most accurate (>73%) for identifying target ADLs. Nevertheless, the authors acknowledged the invasiveness of this approach in terms of resident burden in addition to the requirement for custom 3D models to be generated for each environment.

Other researchers have attempted to develop semi-automatic methods for annotating sensor data. van Kasteren *et al.* [5] asked occupants to use bluetooth headsets and to verbally record ADLs. Voice recognition software was used to interpret statements. While this approach was relatively accurate the authors reported that users quickly became tired of having to verbally describe each activity.

While these studies have reported improvements in annotation processes, as yet there does not appear to exist a method, which alleviates the requirement for occupants to maintain some form of activity log. In the current study, the DANTE system is presented. It is a software-based application, which incorporates a set of stereo cameras to support the recording and annotation of ADLs. Using this tool, the annotation effort can be significantly reduced when compared to manual annotation methods. Furthermore, occupants are not required to maintain written notes relating to which ADLs are being conducted. A technical overview of the operation of the DANTE system has previously been presented [9]. What follows is a brief outline of the system architecture.

3 DANTE System

The system incorporates two stereo MicronTracker cameras [10], which are used to monitor and track the movement of objects within a smart home. The system also supports the use of a single camera, however, incorporating two cameras reduces cases of occlusion and supports an increased field-of-view. The cameras are light-weight and mounted on small tripods therefore allowing for maximum portability (Figure. 1 (a)). At present each camera supports a field-of-view of between 0.5 and 5 meters. The cameras are configured to sample at a frame-rate of up to 10Hz and can track up 30 objects concurrently. This latter limitation is attributed to the processing power of the computer system, which executes the DANTE software. Using a unique reference point within the environment, the two cameras can interpret both the location and orientation of objects in a global coordinate space.

Objects in the current context refer to any item within a home, which needs to be tracked, for example, within a kitchen objects such as cupboards, oven door, taps, cups, plates and food packaging may be tracked. Objects are 'tagged' with paper-based markers, each of which consists of a unique black and white pattern (Figure. 1 (b-c)). The number of unique markers, which can be designed, is practically unlimited as they can differ in both size and pattern. Off-line, each marker is 'learned' by the camera system and labeled in a configuration file to identify the object, to which it is attached.

(a) (b) (c)

Fig. 1. (a) stereo camera set on tripod for portability, (b) fiducial marker attached to cupboard and (c) coffee jar

During recording, each camera captures a number of scenes, where a scene describes a video frame during which tagged objects have appeared/disappeared or moved more than the configurable tolerance parameter within the field-of-view. As a result, DANTE intelligently ignores frames where no change in the environment occurs or where only non-tagged objects are moved. This significantly reduces the amount of data, which is stored therefore simplifying annotation.

A full description of the recording module UI is provided in [9]. Figure 2 only presents a screenshot of a scene captured by one of the cameras and highlights the data, which is recorded by the system. As can be seen, more than one object can be tracked within a single scene. It is important to note that the actual images captured by the camera are only used to support the annotation process and are not used by the software to track objects. The data stored for each scene include the observable objects': ID; label; global coordinates (object position with respect to each camera); orientation and timestamp.

Fig. 2. example scene captured by stereo camera. Also shown is the data stored in relation ot the scene. Included are object: IDs; labels; global coordinates; orientation and; timestamp.

Due the fact that DANTE only records scenes where tagged objects are involved consecutive frames may represent scenes, which are seconds or even minutes apart. This allows for the annotation process to be completed much more efficiently. Figure 3 presents a screenshot of the UI, which is used to support the annotation process.

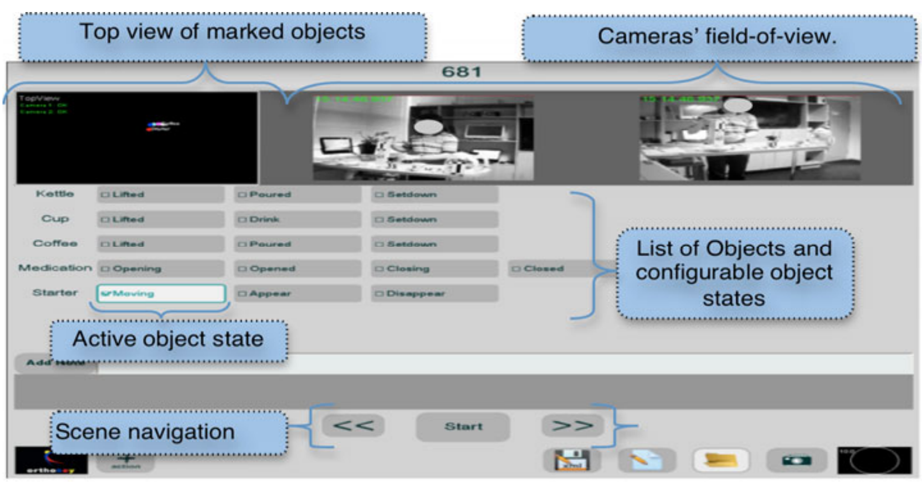

Fig. 3. Labeled screenshot of DANTE annotation UI

A set of annotation terms can be defined in a configuration file to indicate the possible states, which tagged object can possess. For example, a cupboard could be in either an opening, open, closing, or closed state at anytime. By defining annotation terms within a configuration file the system can be customised to support the annotation of objects within any environment. Users simply navigate through scenes, pausing to set/unset object states using onscreen toggle buttons. Free-text annotation is also supported for situations when an unexpected object state is encountered. The annotation process produces an output file (Figure 5) consisting of a list of labelled events with associated time stamps. In the present study, these output files were investigated as a means for assisting with the annotation of two additional sensor platforms.

4 Experimental Outline

This study used a number of sensors from different vendors to monitor the ADLs of drink preparation and taking medication. In the experiments, sensors from 3 different vendors were attached to specific objects (cup, kettle, pill box) within a lab-based kitchen environment [11]. Specifically, each object was tagged with a DANTE marker, a sensor supporting accelerometry (SunSpot by Sun Microsystems) [12] and a contact-sensor (Tynetec) [13]. Figure 4 provides photographs of the environments where ADLs were investigated.

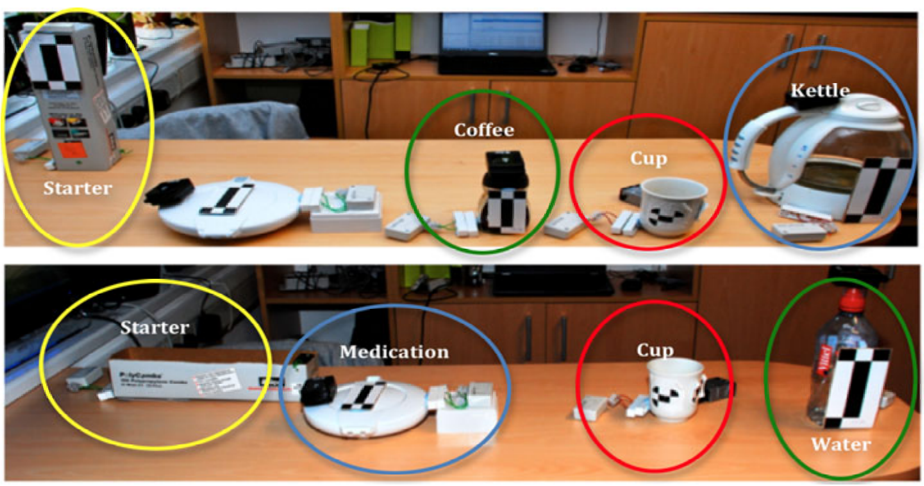

Fig. 4. ADL monitoring experimental setup. The top photo highlights the objects, which were used for drink preparation. The bottom photo highlights the objects, which were used for taking medications. The 'starter' object was used to synchronise the platform timestamps.

Three young healthy male subjects, working in the field of assistive technology were invited to participate. All repeated both ADL activities 3 times resulting in a total of 54 outputs files, representing 18 outputs per sensor platform. During each experiment, participants were asked to conduct a series of steps (Table 1), which took between 2-3 minutes to complete. Instead of asking participants to maintain a diary of their actions as was highlighted to be common practice in Section 2, participants were only instructed when to start each ADL activity. For experimental purposes, an observer ensured that the protocol was adhered to.

Table 1. Presentation of the nesscessary steps involved for each ADL

Drink Preparation	
1.	A 'starter' object was moved to synchronise the timestamps of the three different platforms.
2.	A cup was lifted and repositioned close to the occupant.
3.	A coffee jar was lifted and then opened. Coffee was then added to the cup and then replaced on the table.
4.	A kettle was lifted, water was poured into the cup, and then replaced on the table.
5.	The participant lifted the cup, took a drink and then set the cup down.
6.	The 'starter' object procedure was repeated to indicate an end to the ADL activity.
Taking Medication	
1.	A 'starter' object was moved to synchronise the timestamps of the three different platforms.
2.	A bottle of water was lifted and added to an empty cup.
3.	A medication dispenser was opened, medication extracted and then closed.
4.	The participant lifted the cup, took a drink and then set the cup down.
5.	The 'starter' object procedure was repeated to indicate an end to the ADL activity.

The data recorded from the DANTE system, Tynetec and SunSpot platforms were output to three separate files. Following the recording process, DANTE was used to annotate scenes captured by the stereo cameras. This process was used to produce the gold standard for the experiments given that the ADLs could be validated through the video footage. Figure 5 presents example output files, showing a DANTE annotated output file for the drink preparation ADL. As can be seen from the figure, using timestamp information it was possible to annotate both Tynetec and Sunspot data. For the 'lift cup' action represented in Figure 5, it is interesting to note that the Tynetec data only logged a single event to represent the contact sensor being separated from the cup while the SunSpot, sampling at 1Hz, recorded 3 events as the cup was lifted.

5 Discussion of Experimental Findings

Annotation took 3-5 minutes to complete for each recorded ADL within the DANTE console. Subsequently, timestamps identified by DANTE outputs were used to guide the annotation of the other two sensor platforms. For experimental comparison, a sample of recordings were annotated manually without DANTE. Using only information regarding start time of each ADL, respective sensor IDs were examined to manually identify ADL actions. Manual annotation of Tynetec and SunSpot data took approximately 12 minutes compared to approximately 6.5 minutes when using DANTE to guide this process. Table 2 presents a sample set of results.

An advantage DANTE was that the participants were not themselves responsible for keeping a diary of their actions as DANTE outputs can be viewed akin to a manual record/observer of the events that took place. Nevertheless, while timestamps provided by DANTE were useful to indicate onset and completion of ADL actions within the Tynetec and SunSpot outputs (Figure 5), it should be noted that this was still a manual process, requiring files to be accessed, sorted by sensor ID and compared against DANTE timestamps. Future work will aim to automate the timestamp matching process to reduce the annotation time further.

Table 2. Sample of results highlighting time taken to annotate Tynetec and SunSpot with and without the support of DANTE

	Manual Annotation	DANTE Supported	% Difference
Coffee Prep. 01	14 min 01 sec	07 min 44 sec	44.83%
Coffee Prep. 02	14 min 49 sec	07 min 56 sec	46.46%
Med. 01	12 min 34 sec	06 min 03 sec	51.86%
Med. 02	11 min 46 sec	06 min 31 sec	44.62%
	…		

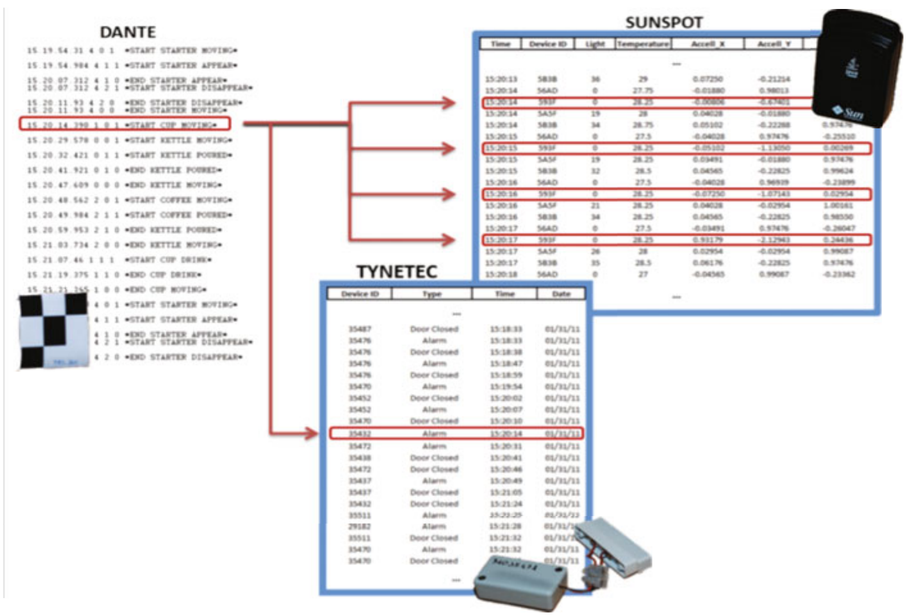

Fig. 5. Example annotated DANTE output with 'lift cup' action highlighted. Using timestamp information, it is possible to identify significant events within non-annotated Tynetec and SunSpot recordings

6 Conclusion

Although experiments focused only on experimental ADLs they do serve to illustrate the utility of DANTE for increasing the efficiency of data annotation. Incorporation of DANTE into a smart environment allows occupants to perform ADLs without having to manually record/describe their activities. Furthermore, it has been shown that DANTE is a suitable tool for assisting with the annotation of different platforms. Using this tool, researchers could aim to collect large amounts of data to identify ADL actions across multiple sensor platforms. Such an approach could be used to highlight the potential benefits and drawbacks of sensor platforms in terms of the contextually rich data they claim to support.

Finally, as highlighted in [9], future work with DANTE will investigate the potential to support automatic annotation whereby activities could be deduced based on the relative positioning and orientation of objects. In additions to further reducing annotation time, an automated process would reduce potential privacy issues as recorded frames would not be required for manual annotation and therefore could be discarded. As a result we believe that the DANTE system can offer significant benefits to the research community in support of data collection.

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Using Association Rule Mining to Discover Temporal Relations of Daily Activities

Ehsan Nazerfard, Parisa Rashidi, and Diane J. Cook

School of Electrical Engineering and Computer Science
Washington State University
Pullman, WA 99164, USA
{nazerfard,prashidi,cook}@eecs.wsu.com

Abstract. The increasing aging population has inspired many machine learning researchers to find innovative solutions for assisted living. A problem often encountered in assisted living settings is activity recognition. Although activity recognition has been vastly studied by many researchers, the temporal features that constitute an activity usually have been ignored by researchers. Temporal features can provide useful insights for building predictive activity models and for recognizing activities. In this paper, we explore the use of temporal features for activity recognition in assisted living settings. We discover temporal relations such as order of activities, as well as their corresponding start time and duration features. To validate our method, we used four months of real data collected from a smart home.

Keywords: Association Rule Mining, Temporal Relations, Clustering, Smart Homes.

1 Introduction

The projection of age demographics shows an increasing aging population in the near future. Today, approximately 10% of the world's population is 60 years old or older, and by 2050 this proportion will be more than doubled. Moreover, the greatest rate of increase is among the "oldest old", i.e. people aged 85 and over [1]. This results in a society where medical and assistive care demands simply cannot be met by the available care facilities. The resulting cost is significant for both government and families. At the same time, many researchers have noted that most elderly people prefer to stay at home rather than at care facilities.

To provide in-home assisted living, smart homes can play a great role. A smart home is a collection of various sensors and actuators embedded into everyday objects. Data is collected from various sensors and is analyzed using machine learning techniques to recognize a resident's activities and environmental situations. Based on such information, a smart home can provide context-aware services. For example, to function independently at home, elderly people need to be able to complete Activities of Daily Living (ADL) [2], such as taking medication, cooking, eating and sleeping. A smart home can monitor how completely

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and consistently such activities are performed, to raise an alarm if needed, and to provide useful hints and prompts.

An important component of a smart home is an activity discovery and recognition module. Activity recognition has been studied by many researchers [3][4]. Unfortunately, most activity recognition methods ignore temporal aspects of activities, and solely focus on recognizing activities as a sequence of events. Exploiting temporal aspects of activities can have tremendous potential applications, especially in an assisted living setting. For example, consider the following classic scenario which shows how temporal features can be useful in an assistive living setting:

Marilla Cuthbert is an older adult who is living alone and is in the early stages of dementia. Marilla usually wakes up between 7:00 AM and 9:00 AM every day. After she wakes up (detected by the activity recognition module), her coffee maker is turned on through power-line controllers. If she doesn't wake up by the expected time, her daughter is informed to make sure that she is alright. Marilla should take her medicine within at most one hour of having breakfast. If she doesn't take her medicine within the prescribed time or takes it before eating, she is prompted by the system. The rest of her day is carried out similarly.

The above scenario shows how temporal features can be useful in an assisted living setting. The discovered temporal information can be used to construct a schedule of activities for an upcoming period. Such a schedule is constructed based on the predicted start time, as well as the relative order of the activities.

In this paper, we propose a framework for discovering and representing temporal aspects of activity patterns, including temporal ordering of activities and their usual start time and duration. We refer to the proposed framework as "TEREDA", short for "TEmporal RElation Discovery of Daily Activities". TEREDA discovers the order relation between different activities using temporal association rule mining techniques [5]. It represents temporal features such as the usual start time and duration of activities as a normal mixture model [6], using the Expectation Maximization (EM) clustering method [7]. The discovered temporal information can be beneficial in many applications, such as for home automation, for constructing the schedule of activities for a context-aware activity reminder system, and for abnormal behavior detection in smart homes.

2 Related Work

The concept of association rules was first proposed by Agrawal et al. [8] to discover what items are bought together within a transactional dataset. Since each transaction includes a timestamp, it is possible to extend the concept of association rules to include a time dimension. This results in a new type of association rules are called temporal association rules [5]. This extension suggests that we might discover different rules for different timeframes. As a result, a rule might be valid during certain timeframe, but not during some other timeframes.

Activity pattern dataset in smart homes also include a timestamp. The timestamp implies when a particular activity has performed, or more specifically when a specific sensor was triggered. Similar to association rule mining, considering the concept of temporal features to the activity patterns can be quite useful. For instance, in a home automation setting, we can determine when a certain activity is expected to occur and which activities are most likely to occur next. Despite the potential use of temporal features in activity patterns, this key aspect is usually neglected and has not been exploited to its full potential.

One of the few works in this area is provided by Rashidi et al. [4], in the form of an integrated system for discovering and representing temporal features. They only consider start times of activities at multiple granularities, and do not address discovering other important temporal features and relations such as the relative order of activities. Galushka et al. [9] also discuss the importance of temporal features for learning activity patterns, however they do not exploit such features for learning activity patterns in practice. Jakkula and Cook [10] show the benefit of considering temporal associations for activity prediction. Their main focus is on investigating methods based on using Allen's temporal logic to analyze smart home data, and to use such analysis for event prediction.

3 Model Description

The architecture of TEREDA is illustrated in Fig. 1. TEREDA consists of two main components: the temporal feature discovery component and the temporal relation discovery. Each component will be described in more depth in the following sections. The input dataset consists of a set of sensor events collected from various sensors deployed in the space. Each sensor event consists of an ID and a timestamp. To make it easier to follow the description of our model, we consider an example "wash Dishes" activity throughout our discussions.

3.1 Temporal Activity Features Discovery

For each activity, we consider the *start time* of the activity and the *duration* of the activity. After extracting the start times of all instances of a specific activity, we cluster the start times to obtain a canonical representation. For this purpose we use the Expectation Maximization (EM) clustering algorithm [7] to construct a normal mixture model for each activity.

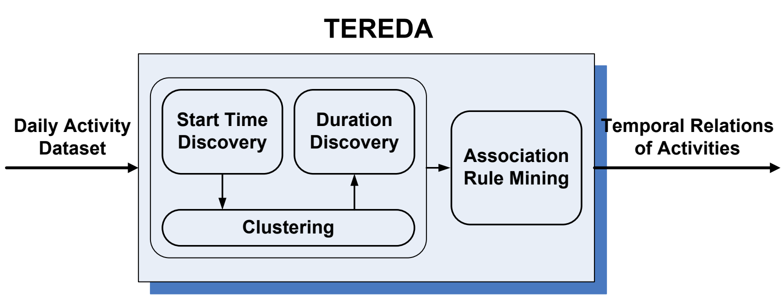
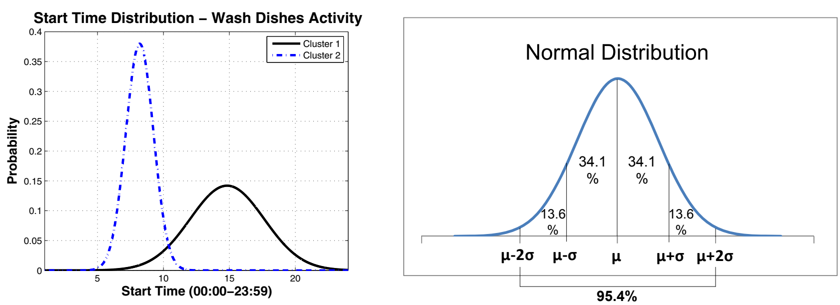


Fig. 1. TEREDA architecture

Lets denote the start time of activity a_i by t_i. Then the probability that t_i belongs to a certain cluster k can be expressed as a normal probability density function with parameters $\Theta_k = (\mu, \sigma)$ as in Equation 1. Here μ and σ are the mean and standard deviation values, calculated for each cluster of start times.

$$prob(t_i|\Theta_k) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{(t_i-\mu)^2}{2\sigma^2}} \quad (1)$$

The parameters of the mixture normal model are computed automatically from the available data. The results of finding the canonical start times of the "Wash Dishes" activity can be seen in Fig. 2a as a mixture of two normal distributions. According to the normal distribution features, the distance of "two standard deviations" from the mean accounts for about 95% of the values (see Fig. 2b). Therefore if we consider only observations falling within two standard deviations, observations that are deviating from the mean will be automatically left out. Such observations that are distant from the rest of the data are called "outlying observations" or "outliers".



(a) A mixture model for the start time of "Wash Dishes" activity

(b) Outlier detection based on normal distribution features

Fig. 2. A mixture normal model and normal distribution characteristics

Besides the start time, we also consider the duration of an activity. For each resulting cluster of the start time discovery step, we calculate the average duration of all instances fallen in that cluster.

3.2 Temporal Activity Relations Discovery

Discovering the *temporal relations* of activities is the main component of TEREDA. The input to this stage is the features discovered in the previous stage, i.e. the canonical start times and durations. The output of this stage is a set of temporal relations between activities. The temporal relations will determine the order of activities with respect to their start times, i.e. for a specific time what are the most likely activities that follow a specific activity. Such results can be useful in a variety of activity prediction scenarios. To discover the temporal relations of activities, we use the Apriori algorithm [8].

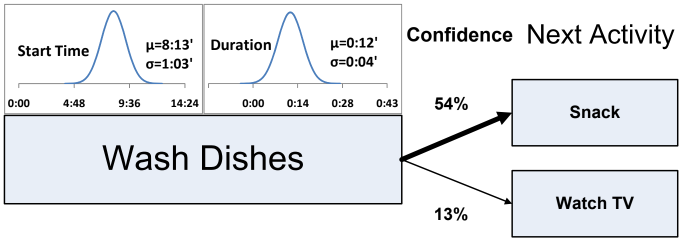


Fig. 3. Temporal relations of the 1st cluster of "Wash Dishes"

To describe the temporal relation discovery component more precisely, lets denote an instance i of an activity a by a_i. The successor activity of a_i in the dataset is denoted by b_j, where j refers to the instance index of activity b. Also as mentioned in the previous section, each activity instance belongs to a specific cluster Θ_k that is defined by the start time of the activity instance. Furthermore, to show that an activity a_i belongs to a specific cluster Θ_k, we denote it by a_i^k. Finally, we will show the temporal relation "b follows a" as $a \rightarrow b$.

Denoting the mean and standard deviation of cluster k as μ_k and σ_k, we refer to the number of instances of all activities and activity a falling within $[\mu_k - 2\sigma_k, \mu_k + 2\sigma_k]$ interval as $|D^k|$ and $|a^k|$ respectively. Then we can define the support of the "follows" relation as in Equation 2 and its confidence as in Equation 3.

$$supp(a^k \rightarrow b) = \frac{\sum_{i,j} (a_i^k \rightarrow b_j)}{|D^k|} \tag{2}$$

$$conf(a^k \rightarrow b) = \frac{\sum_{i,j} (a_i^k \rightarrow b_j)}{|a^k|} \tag{3}$$

The result of this stage is a set of temporal relation rules corresponding to each cluster. Fig. 3 illustrates the discovered temporal relation rules, whose confidence values are greater than 0.1, for the first cluster of the "Wash Dishes" activity. According to Fig. 3, if "Wash Dishes" activity occurs in the time interval $[7\colon 35, 8\colon 51]$, it usually takes between 4 to 20 minutes and the next activities are typically "Snack" with a confidence of 0.54 and "Watch TV" with a confidence of 0.13.

4 Experimental Results

In this section, the experimental results of TEREDA are presented. Before getting into the details of our results, we explain the settings of our experiment.

4.1 Experimental Setup

The smart home testbed used in our experiments is a 1-bedroom apartment hosted two married residents who perform their normal daily activities. The

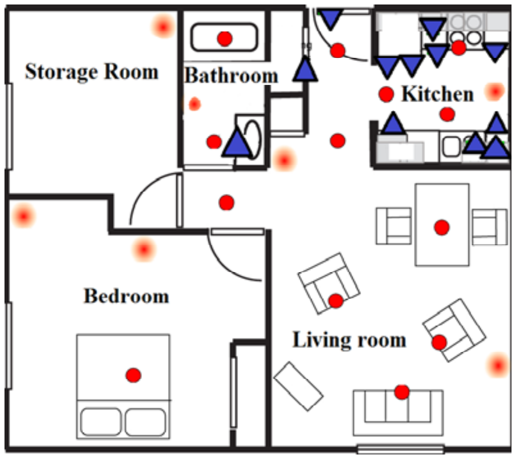


Fig. 4. The sensor layout in the 1-bedroom smart home testbed, where circles represent motion sensors and triangles show door/cabinet sensors

Table 1. EM clustering and Apriori parameters

EM clustering	Max Iterations = 100
	Min Standard Deviation = $1.0e-6$
	Seed = 100
Apriori	Min Support = 0.01
	Min Confidence = 0.1

sensor events are generated by motion and door/cabinet sensors. Fig. 4 shows the sensor layout of our smart home testbed. To track the residents' mobility, we use motion sensors placed on the ceilings and walls, as well as on doors and cabinets. A sensor network captures all the sensor events, and stores them in a database. Our training data was gathered over a period of 4 months and more than 480,000 sensor events were collected for this dataset[1]. For our experiments, we selected 10 ADLs including: Cook Breakfast, R1 Eat Breakfast, R2 Eat Breakfast, Cook Lunch, Leave Home, Watch TV, R1 Snack, Enter Home, Wash Dishes, and Group Meeting; where R1 and R2 represent the residents of the smart home.

Moreover, Table 1 depicts the parameter values for the Expectation Maximization (EM) clustering and Apriori association rule mining in our experiments.

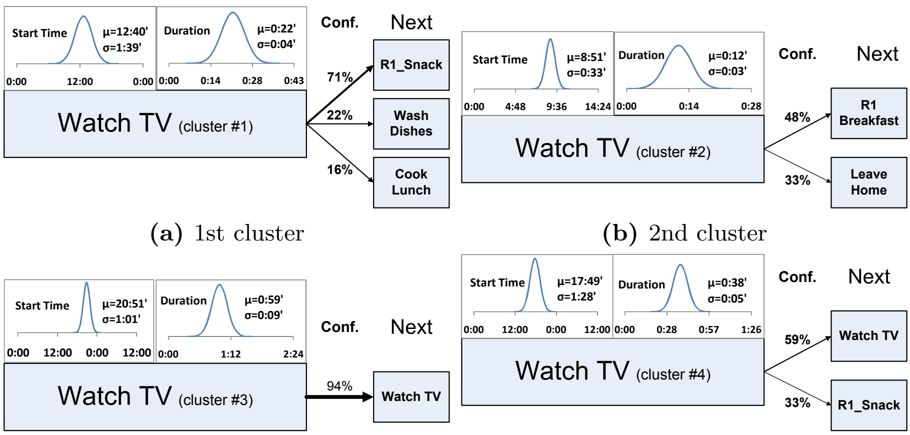
4.2 Validation of TEREDA

In this section, we provide the results of running TEREDA on the smart home dataset. Table 2 shows the number of clusters corresponding to start times of each activity after running TEREDA on the dataset.

[1] Availavle online at http://ailab.eecs.wsu.edu/casas/datasets.html

Table 2. Number of start time clusters for each activity

Activity	# of clusters	Activity	# of clusters
Cook Breakfast	2	R1 Eat Breakfast	2
Cook Lunch	1	R1 Snack	5
Enter Home	3	R2 Eat Breakfast	2
Group Meeting	1	Wash Dishes	2
Leave Home	2	Watch TV	4



(a) 1st cluster **(b)** 2nd cluster

(c) 3rd cluster **(d)** 4th cluster

Fig. 5. Temporal relations of the "Watch TV" activity

The discovered temporal relations for "Watch TV" activity is illustrated in Fig. 5. As mentioned in subsection 3.1, in order to handle outliers, we only retain values within the [μ-2σ, μ+2σ] interval for start time of each activity. According to Fig. 5a, if activity "Watch TV" occurs in the [9: 22, 15: 58] timeframe, the activity takes approximately 14 to 30 minutes. This activity is typically followed by the "R1 Snack", "Wash Dishes" or "Cook Lunch" activities. The likelihood of occurrence of "R1 Snack" is 0.71, while "Wash Dishes" and "Cook Lunch" occur with likelihoods of 0.22 and 0.16, respectively. Furthermore, Fig. 5b indicates that when "Watch TV" occurs between 7: 45 and 9: 57, it takes approximately 6 to 18 minutes and the next likely activities are "R1 Breakfast" with a confidence of 0.48 and "Leave Home" with a likelihood of 0.33. Moreover, Fig. 5c shows that when the "Watch TV" activity is performed within the timeslice [18: 49, 22: 53], it usually takes around 41 to 1: 17 minutes. In this case, "Watch TV" is most likely followed again by "Watch TV" with a confidence of 0.94. Finally, Fig. 5d shows temporal features and relations of the "Watch TV" activity when it occurs within the [14: 53, 20: 45] interval. In this time interval, the "Watch TV" activity takes approximately 28 to 48 minutes and the next activities are "Watch TV' with a confidence of 0.59 and "R1 Snack" with a confidence of 0.33.

5 Conclusions and Future Work

In this paper, we introduced TEREDA to discover the temporal relations of the activities of daily living. The proposed approach is based on association rule mining and clustering techniques. TEREDA also discovers the usual start time and duration of the activities as mixture normal model. As a future direction, we are planning to use these discoveries in developing activity reminder and abnormal behavior detection systems.

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Using Graphs to Improve Activity Prediction in Smart Environments Based on Motion Sensor Data

S. Seth Long and Lawrence B. Holder

Washington State University

Abstract. Activity Recognition in Smart Environments presents a difficult learning problem. The focus of this paper is a 10-class activity recognition problem using motion sensor events over time involving multiple residents and non-scripted activities. This paper presents the results of using three different graph-based approaches to this problem, and compares them to a non-graph SVM approach. The graph-based approaches are generating feature vectors using frequent subgraphs for classification by an SVM, an SVM using a graph kernel and nearest neighbor approach using a graph comparison measure. None demonstrate significantly superior accuracy compared to the non-graph SVM, but all demonstrate strongly uncorrelated error both against the base SVM and each other. An ensemble is created using the non-graph SVM, Frequent Subgraph SVM, Graph Kernel SVM, and Nearest Neighbor. Error is shown to be highly uncorrelated between these four. This ensemble substantially outperforms all of the approaches alone. Results are shown for a 10-class problem arising from smart environments, and a 2-class one-vs-all version of the same problem.

1 Introduction

Activity Recognition in Smart Environments is made difficult by the dynamics of everyday life, particularly in settings involving multiple residents without a particular set of activities to perform. Activities are seldom performed in exactly the same way from one time to the next, particularly if the resident is multitasking.

The Washington State University Smarthome project uses motion sensors to detect activity within a dwelling. These sensors are placed in strategic locations in order to report relevant information on the inhabitant's location (Figure 1).

The focus of this paper is a 10-class activity recognition problem arising from this project. Two residents and a pet lived in the smart environment in Figure 1. Data from the motion sensors during this period is annotated with 10 different activity labels, for non-overlapping activities. Not all the collected data is associated with one of these 10 activities, and data annotated with a particular activity label may contain sensor events not related to the activity in question. A simple SVM-based classifier (described in Section 3) gives a baseline accuracy of 68% in determining the correct activity label (using cross-10 validation).

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In order to improve upon this baseline accuracy, this paper presents a method of considering an activity to be a graph, and three graph-based approaches to improve accuracy. Frequent Subgraph SVM uses presence or absence of a set of frequent subgraphs to generate a feature vector, which is then classified by a standard SVM.Graph Kernel SVM uses a kernel which compares graphs directly based on the number of similar walks. Nearest Neighbor uses a graph comparison function as a distance measure for a Nearest Neighbor algorithm. Each of these three graph-based methods, along with the non-graph SVM, are shown to have uncorrelated error. An ensemble of these three plus the baseline method yields higher accuracy than any of the methods alone.

The Cairo test environment (Figure 1) consists of a 3-bedroom apartment with two residents and two types of sensors relevant to this work. Limited area motion sensors report any motion within an area of about a square meter. Area motion sensors report any motion within a room. The 10 labeled activities are: Work in office (46), Take medicine (44), Sleep (102), Night Wandering (67), Lunch (37), Leave Home (69), Laundry (10), Dinner (42), Breakfast (48), Bed to Bathroom (30). The number in parenthesis is the number of times the indicated activity occurs in the dataset. The learning algorithms are provided with motion sensor data only. Certain other attributes such as time [5] have proven to be useful as well, but are not considered in this work.

2 Previous Work

Deshpande et al. use feature vectors created from frequent subgraphs to analyze chemical structures in [7]. Feature vector generation is separated from classification, so that any classification algorithm can be used. Deshpande et al. use a Support Vector Machine. This is similar to the Frequent Subgraph SVM used in this work.

Graph-based kernels for Support Vector Machines, including the direct product kernel used in this paper, are described by Gärtner et al. in chapter 11 of Mining Graph Data [4] and in [8]. It is compared with a cycle-based kernel, which is quicker to compute but results in reduced accuracy.

Nearest Neighbor algorithms using graph edit distance were used in [11]. This approach was tested here, but accuracy was not as good as the system of points defined in Section 3.

Much research has been done on the Smarthome project. Singla et al. [1] use a Naive Bayes Classifier and Hidden Markov Model to classify activities similar to the ones in this paper, although generated in a more scripted manner and in a different living space. They present results on an 8-class problem of a similar nature. Kim et al. [9] provide a theoretical overview of the task, using Hidden Markov Models, Conditional Random Field, and Emerging Patterns. Crandall and Cook use a Naive Bayes Classifier and Hidden Markov Models to distinguish multiple inhabitants in a smart environment [6].

The frequent substructures are discovered by Gaston [12], an established frequent subgraph miner for which the source code is available. The Support Vector Machines use libsvm [2], a freely available Support Vector Machine library.

Fig. 1. The left two graphs are both of breakfast. Both include many sensor events outside the usual area of the activity. The rightmost picture is a frequent subgraph among all breakfast graphs.

3 Methods Used

A graph is constructed out of a sequence by considering each sensor to be a node, and connecting two sensors if they are visited in sequence. Figure 1 shows examples of graphs generated by such a process. No attempt is made to avoid connecting sensors which cannot physically be visited in sequence. This becomes significant when there are two inhabitants performing possibly different activities at the same time and in different locations within the environment.

Non-Graph SVM. A graph-unaware Support Vector Machine using a Radial Bias Function kernel was used as a representative of the non-graph-based approach. Support Vector Machines are a leading classification method [10] [2] [13], and the Radial Bias Function is a good general-purpose kernel given appropriate parameters [2] [15]. Input was given as feature vectors containing only the sensors triggered in a particular activity. This is represented as a vector of booleans, and is equivalent to the node labels in a graph representing the event.

Frequent Subgraph SVM. As indicated in figure 1, a graph of an activity may contain many extraneous edges. However, some edges will be common in all graphs from that activity. Figure 1 shows a graph which is common to all activities classified as "breakfast". A graph which contains this subgraph is more likely to represent the activity "breakfast" than one that does not.

A set of frequent subgraphs was found for each of the 10 classes. The presence or absence of each of these subgraphs in a graph to be classified was used to form a feature vector. A subgraph was only considered present if all of the edges in it are represented in the graph to be classified, with the requirement that the node labels match exactly. This allows the classifier to exploit the fact that particular activities tend to take place in particular locations.

Once the data is represented as a set of feature vectors, it can be classified using standard learning algorithms. An SVM with RBF kernel obtained higher accuracy than a decision tree algorithm, a naive Bayes classifier, and an artificial neural net.

SVM with Graph Kernel. Support Vector Machines do not interact directly with the examples they are classifying, but rather use a kernel function which returns a similarity measure. Training and test examples are given directly to this kernel function. Therefore, if a kernel function is used which takes as input a pair of graphs rather than a pair of feature vectors, a support vector machine can operate on graphs.

A direct product kernel [4] was used to compare graphs. This kernel compares walks in two graphs to determine similarity. It depends heavily on cross product between graphs. Consider a graph without edge labels to be represented as a set of vertexes V, a set of edges E, and a set of node labels α such that $G = (V, E, \alpha)$. The cross product of two graphs $g_1 = (V_1, E_1, \alpha_1)$ and $g_2 = (V_2, E_2, \alpha_2)$, is defined as $g_1 \times g_2 = (V_{g_1 \times g_2}, E_{g_1 \times g_2})$, where

$$V_{g_1 \times g_2} = \{(v_1, v_2) \in V_1 \times V_2 : \alpha_1(v_1) = \alpha_2(v_2)\}$$
$$E_{g_1 \times g_2} = \{((u_1, u_2), (v_1, v_2)) \in V_{g_1 \times g_2} \times V_{g_1 \times g_2} : (u_1, v_1) \in E_1, (u_2, v_2) \in E_2\}$$

Node are labeled for the sensor they represent. Labels do not need to directly appear in $g_{g_1 \times g_2}$, given that the following definition of the direct product kernel depends only on the adjacency matrix of $g_{g_1 \times g_2}$. The direct product kernel is defined by:

$$k(g_1, g_2) = \sum_{i,j=1}^{|V_{g_1 \times g_2}|} \left[\sum_{l=0}^{\infty} M_{g_1 \times g_2}^{l} \right]_{ij}$$

Entries in the adjacency matrix $M_{g_1 \times g_2}$ correspond to the number of walks between nodes i and j of length l. 10 is used as a computationally-feasible substitute for ∞. As noted in [8], graph kernels are computationally expensive. An $O(n^3)$ algorithm is proposed in [14], but was not used for this work. All values from this kernel were precomputed in parallel using a 296-node cluster.

Nearest Neighbor. Nearest Neighbor algorithms can be adapted to classify graphs given a suitable distance measure between graphs. This can be provided in a number of ways. The method used here is to assign "similarity points". 1 point is given for a matching node or edge in both graphs, and 4 points is lost for a node which cannot be matched in the other graph. This is intended to emphasize the location of the event, while still giving some consideration to the patterns of movement during it. This was converted into a distance by $1/points$ if more than three points were obtained, and a maximal distance of 1 otherwise. Accuracy is not greatly affected by changing the point values.

Some work has been done on using graph edit distance with a nearest neighbor algorithm [11]. This was tried using the "graph match" feature from Subdue [3]. This feature gives a "matching cost" which can be adapted to serve as a distance. This resulted in lower accuracy and required more time to run, and was not pursued further.

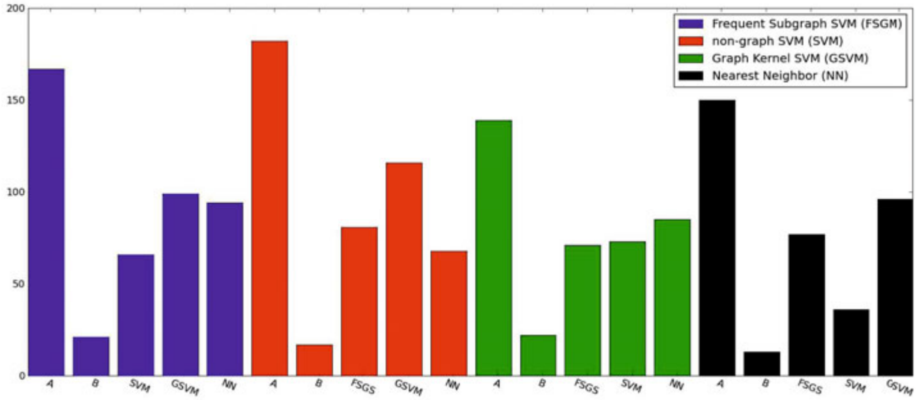

Fig. 2. Error correlation of all 4 methods. A indicates the number of times the indicated (by color) method was right and at least one other method was wrong. B indicates the number of times the indicated method was right, and all other methods were wrong. Each of the remaining three bars of each color represent the number of times the method indicated by color was right, when the method indicated by label was wrong.

Ensemble. An ensemble of all 4 techniques mentioned above was used to increase performance beyond any of the methods alone. Weights were assigned such that a ranking of Frequent Subgraph SVM, the non-graph SVM, Nearest Neighbor, Graph Kernel SVM was established and no algorithm has more than twice the weight of any other. This is a ranking from most accurate algorithm to least.

4 Results

Accuracy obtained for each method, using 10-cross validation on the 10-class problem, was 66.66 for Subgraph SVM, 66.0 for Non-graph SVM, 58.5 for Graph SVM, 60.5 for Nearest Neighbor, and 72.5 for an ensemble of the previous four. The conditions for a successful ensemble are reasonably accurate classifiers and uncorrelated error. Error correlations are given in Figure 2. There are 53 examples that no algorithm classifies correctly, 73 correctly classified by exactly one algorithm, 89 by two, 129 by three, and 151 by all four. On 11 examples, two algorithms are correct but are outvoted by a higher-weighted pair of algorithms. The Nearest Neighbor algorithm appears to be the least useful in this comparison, however, when removed from the ensemble the overall accuracy drops to 70.1%.

There are 73 test examples which are only classified correctly by one algorithm. The voting weights used ensure that in all these 73 cases, the answer from the frequent subgraph SVM is used (this resulted in greater overall performance than using the graph kernel SVM in this role). This results in 52 misclassifications, out of 136 misclassifications total. In addition to these 52, there are 11

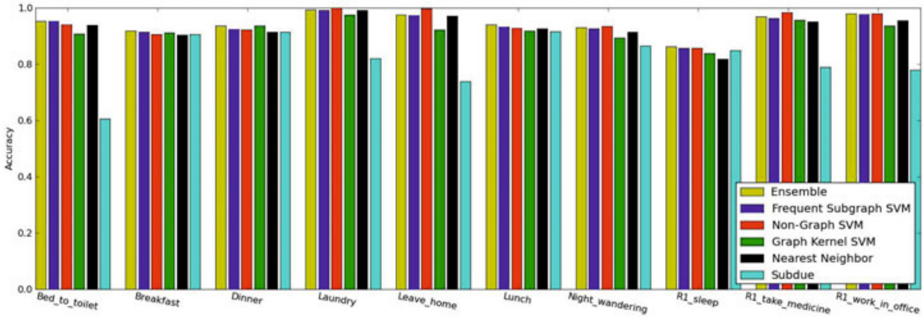

Fig. 3. Comparison on 2-class one-vs-all problems. 3-cross validation used for accuracy.

Class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Bed to toilet (1)		1.0	0.98	0.87	0.92	0.98	0.87	0.75	0.97	0.88
Breakfast (2)	1.0		0.72	1.0	1.0	0.75	0.99	1.0	0.97	0.98
Dinner (3)	0.98	0.72		0.98	0.99	0.73	0.99	0.99	0.96	0.97
Laundry (4)	0.87	1.0	0.98		0.96	0.97	0.97	0.97	0.96	1.0
Leave home (5)	0.92	1.0	0.99	0.97		0.99	0.99	1.0	0.99	1.0
Lunch (6)	0.98	0.75	0.73	0.97	0.99		0.99	0.99	0.96	0.97
Night wandering (7)	0.87	0.99	0.99	0.97	0.99	0.99		0.76	0.96	0.88
Sleep (8)	0.75	1.0	0.99	0.97	0.98	0.99	0.76		0.97	0.92
Take medicine (9)	0.97	0.97	0.96	0.96	0.98	0.96	0.96	0.97		0.95
Work in office (10)	0.88	0.98	0.97	1.0	0.99	0.97	0.88	0.92	0.94	

Fig. 4. Table showing the accuracy in distinguishing one class from another using the ensemble. The three meals are the most difficult to distinguish from each other, followed by sleep, night wandering, and bed to toilet. Entries in blue indicate greater than 95% accuracy. Entries in red indicate accuracy below 80%.

cases where two algorithms agree on the correct solution, but are outvoted by the other two algorithms, which have greater weight. Only 53 examples are not classified correctly by any algorithm. Weighting is irrelevant for 280 examples correctly classified by at least three algorithms.

2-Class Comparison. In order to determine which categories are particularly easy and hard to distinguish from all the others, a one-vs-all 2-class comparison is used. Accuracy in differentiating each class from all the others is calculated, as in Figure 3. Note that given the 10-class problem, an algorithm which simply guesses the majority class in every case (that is, that the example presented to it is not of the class under consideration) would score 90% accuracy on average. As such, it is unsurprising that nearly every accuracy calculated was above 90%.

The classes showing good performance do not correspond with those with high or low prevalence. Laundry is one of the most successful classes, with the non-graph algorithm scoring a perfect 100%, and the ensemble missing only a single example, and is the least frequent class. Leave Home is the second most frequent class, and is also perfectly distinguished by the non-graph approach

(100% accuracy), as well as the third highest accuracy that the ensemble scored on any category. Sleep is the hardest category to distinguish, followed by Night Wandering (which produces particularly dissimilar graphs) and the three meals.

Figure 3 was generated using optimal parameters for each algorithm, for each category. Frequent Subgraph SVM and non-graph SVM vary in performance based on the RBF kernel parameter γ and the SVM parameter C. Using optimal parameters for each category, rather than a single set of parameters for all categories, gives a fair assessment of the difficulty of each 2-class problem.

One vs One Comparison. The 2-class comparison of Figure 3 provides a good indication of which categories are particularly easy or hard, but not which categories they are easily mixed up with. Figure 4 addresses this problem. The majority of pairs of activities can be distinguished with greater than 95% accuracy (33 out of 45, or 73%). As expected, classes which resulted in high accuracy in Figure 3 are not easily confused with any other class. For example, Laundry can be distinguished from 9 out of 10 other classes with greater than 96% accuracy, the remaining category (bed to toilet) with 87% accuracy. Take medicine, can be distinguished from every other category with 95% or greater accuracy.

In the case of the three meals, the meals are well distinguished from non-meal activities but not each other. Breakfast is traditionally defined as the first meal of the day, and given this definition no machine learning is required at all to differentiate it from other meals. Replacing all three meals with one generic "meal" activity label results in 81.8% overall accuracy.

5 Conclusion

Representing time-based sensor data as a graph provides additional information which is useful for classification. Although none of the graph-based algorithms significantly outperformed the non-graph SVM, they provided uncorrelated error which demonstrates that the graph-based approach is capable of correctly classifying graphs which cannot otherwise be classified correctly. Additionally, the different graph approaches used in the ensemble (Frequent Subgraph SVM, Graph Kernel SVM, and Nearest Neighbor) had uncorrelated error with each other.

This is a useful result in terms of overall classification accuracy. The ensemble gains 6.5% over the best classifier alone on the 10-class problem. It is also a promising result. If three graph-based classifiers with uncorrelated error on this problem exist, there may be others as well.

More work is needed to characterize when each classifier succeeds and fails. A complete success in this area would increase accuracy by over 12%, simply by correctly classifying the examples for which at least one classifier had the correct solution.

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An Accompaniment System for Healing Emotions of Patients with Dementia Who Repeat Stereotypical Utterances

Chika Oshima[1], Naoki Itou[2], Kazushi Nishimoto[3], Naohito Hosoi[4], Kiyoshi Yasuda[5,6], and Koichi Nakayama[7]

[1] Saga University, 1 Honjo, Saga, 8408502 Saga, Japan
chika-o@ip.is.saga-u.ac.jp
[2] School of Knowledge Science, Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, 9231292 Ishikawa, Japan
n-itou@jaist.ac.jp
[3] Center for Knowledge Science, Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, 9231292 Ishikawa, Japan
knishi@jaist.ac.jp
[4] Satsuki Sodegaura of a Medical Corporation, 5-21 Nagauraekimae, Sodegaura, 2990246 Chiba, Japan
hosoi@mail.satsuki-kai.or.jp
[5] Holistic Prosthetics Research Center, Kyoto Institute of Technology, Hashikami-tyo, Matsugasaki, Sakyo-ku, 6068585 Kyoto, Japan
fwkk5911@mb.infoweb.ne.jp
[6] Chiba Rosai Hospital, 2-16, Tatsumidai Higashi, Ichihara, 2900003 Chiba, Japan
[7] Graduate School of Science and Engineering, Saga University, 1 Honjo, Saga, 8408502 Saga, Japan
knakayama@is.saga-u.ac.jp

Abstract. Our research aim is that even caregivers who are musical novices perform part of a music therapy activity. In this paper, we present an accompaniment system for calming the symptoms of patients with dementia with mental instability who repeat stereotypical behaviors and utterances. This system converts patients' utterances into pitches in response to an operator's key entry and automatically plays a cadence based on those pitches. The cadence begins on a chord that resonates with a patient's emotions and finishes on a chord that calms his symptoms. Because the use of this system is simple, even musical novices can use it to calm dementia patients' continuous stereotypical utterances.

Keywords: music, caregiver, convert into the musical notes from the sounds.

1 Introduction

Music therapy is one of the methods known to alleviate symptoms of dementia. Dementia is a deterioration of intellectual function and other cognitive skills by an organic disorder (such as Alzheimer's disease, Dementia with Lewy bodies, Vascular dementia, and so on). The "Behavioral and Psychological Symptoms of Dementia

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(BPSD)" include wandering behavior, hallucinations, delusions, and others, but appropriate care is thought to alleviate and slow down the progression of these symptoms. A music therapist may therefore be requested to visit a nursing home on occasion to perform music therapy to alleviate BPSD.

Clark [1] found that playing recorded music could reduce the occurrences of aggressive behavior among the patients with dementia during bathing episodes. Ragneskog, et al. [2] showed that several caregivers had successfully used music to calm individual agitated patients. In the "Validation [3]," one of the methods used for communication between clients and therapists, a therapist will observe the mood of a client and will emit the same tone with his voice to indicate that he sympathizes with the patient. Likewise, the "Iso-Principle [4]," which is one of the principles of music therapy, suggests that a music therapist first perform music that matches the current mood of a patient and that they then lead the patient to a different mood by gradually changing the mood of the music. This type of therapy is also effective for symptoms in which patients repeat stereotypical behaviors and utterances, such as occur with the mental instability of dementia. Our opinion is that if caregivers, even those who are musical novices, can address these dementia symptoms with music, their patients would become calmer and happier.

In this paper, we present an accompaniment support system that allows musical novice caregivers to calm the repetitive stereotypical behaviors and utterances of patients with dementia. This system converts the patients' utterances into pitches at a predetermined interval. In response to an operator's (e.g., a caregiver's) simple key entry, the system automatically plays a cadence based on those pitches. The cadence begins on a chord that resonates with the patient's current emotions and finishes on a chord that calms his symptoms.

2 Patients Who Repeat Stereotypical Behaviors and Utterances

In this section, we show some examples of patients who repeat stereotypical behavior and utterances. We recorded their utterances with mental instability for one month. Table 1 shows their symptomatic state, the cause of their dementia, their daily attitude, and the situation at the time of recording. The term "HDS-R (Revised Hasegawa's dementia scale) [5]" in the table refers to an intelligence test consisting of 9 simple questions, with a maximum score of 30. A score over 21 score identifies a person who is not a patient. The average score of a patient with mild dementia is 19.1, those with moderate dementia have mean scores of 15.4, and those with severe dementia have scores of 10.7.

The scores in the table show that most of these patients had severe dementia. Even patients who had mild dementia (i.e., Patients C and I) showed mental instability and repeated utterances. The examples show that the patients uttered a strange noise with emotion, calling for someone who was not there or for a caregiver. Even after the caregiver responded to their requests, several of them repeated the same requests, as seen with Patient A. In most cases, we could not understand what the patients were saying. Although doctors, nurses, and caregivers talked to the patients and led them to another action, it was not easy to calm them down. Therefore, music that could resonate with the patients' emotions and calm their symptoms would be expected to help the caregivers in caring for these patients.

Table 1. Data of stereotypical utterances with mental instability

Patients	cause of dementia	sex	age	HDS-R	daily attitude
	situation at the time of recording				
A	Alzheimer	female	89	7	She cries "I want to go to the restroom!"
	She repeated "Neeee" in a falsetto.				
B	Cerebrovascular	male	58	3	irritable, act menacingly, behave rudely
	He repeated "Try not to bother someone," "Please" in tears.				
C	Cerebrovascular	female	77	20	stereotypical utterances.
	She repeated "*taka? (Did you do it?)" in a falsetto.				
D	Alzheimer	female	69	inoperativeness	She utters meaningless sounds.
	She cried "Aaaa" in a loud whisper.				
E	Alzheimer	female	78	inoperativeness	severe symptoms.
	She repeated "Help me!" in a loud voice.				
F	Alzheimer	female	90	inoperativeness	She hang around in crying in a loud voice.
	She repeated meaningless sounds thickly.				
G	Alzheimer	male	78	inoperativeness	irritable, cry in a loud voice.
	He uttered meaningless sounds.				
H	Alzheimer	female	82	inoperativeness	She utteres in a loud voice, poor communication.
	She talked in anger. However, we cannot understand what she said.				
I	frontotemporal	female	70	17	good communication, stereotypical utterances.
	She locked herself in a bathroom, and repeated "*tadesuyo (I did it)"in a loud voice.				
J	Lewy bodies	female	83	13	irritable
	She repeated "Bakayaro (gumby)" with a furious voice.				

3 Set up System

3.1 Outline of the System

We present an accompaniment support system that performs one of a variety of cadences when an operator (e.g., a caregiver) pushes any of the keys of the electronic keyboard, which can output MIDI (Musical Instrument Digital Interface) music. By cadence, we mean a harmonic sequence, such as is often found in the middle and at the end of pieces of music. It brings anticipation to continuous music or indicates completion of music. In this paper, we picked out 96 perfect cadences from established music scores to use as a database of cadences. The cadences were picked from the beginning of an unsteady or/and agitated chord (i.e., a dissonance chord) on the basis of our determination. The unsteady or/and agitated chord may resonate with a patient's mental instability. Then, the cadence aims towards a steady and mild chord, (i.e., a consonance), and finally a terminative chord that is expected to calm down the patient's emotions.

The system also continuously converts the patient's utterances into pitches. In response to the operator's key entry, the system determines a pitch at a predetermined interval. The system selects a cadence in the database on the basis of that converted pitch. The top note of the first chord is same as the pitch converted from the patient's utterances.

Table 1 shows the database of the cadences and the process of the system after a key entry by the operator. The 96 cadences are considered to consist of two types of cadences. The first type of cadence begins with an extremely agitated chord (We call it a “Black-type cadence” in this paper). The other type of cadence begins with a milder, but unsteady chord (We call it a “White-type cadence” in this paper). The operator can easily choose from these types depending on the patient’s condition. When he touches any black key (or any white key) on the keyboard, the Black-type (or the White-type) cadence is output through a speaker.

We will explain how to convert the patient’s utterances into pitches in section 3.2, and provide details of the cadences in section 3.3.

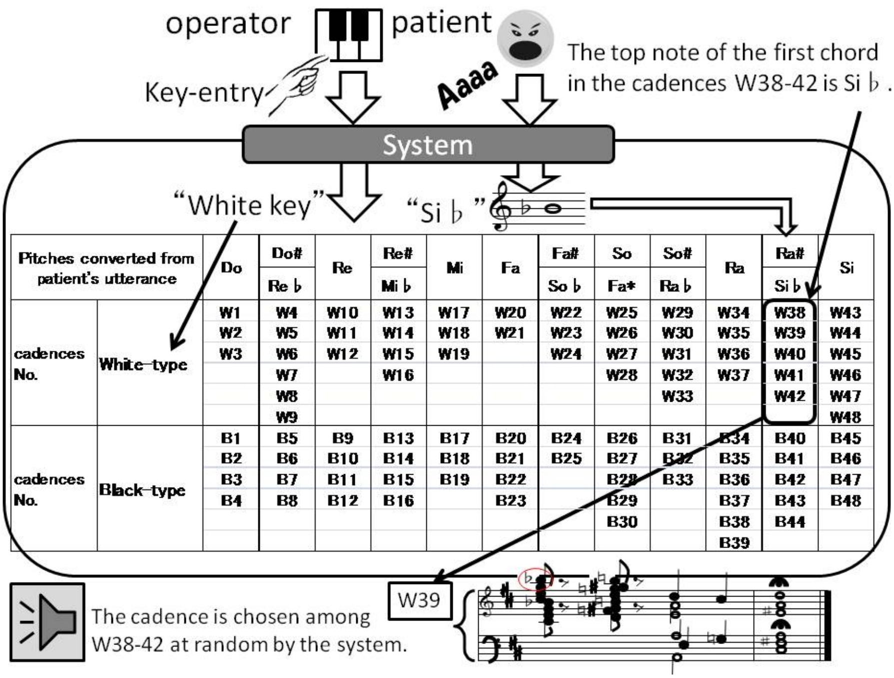

Fig. 1. Selection of a cadence

3.2 Converting the Patient’s Utterances into Pitches

In our research, we employ a pitch extractor to convert the utterance of a patient into one pitch (i.e., Do, Re, Mi). It is based on the technique shown by [6] for conversion of sounds that have unstable pitches and unclear periods, like natural ambient sounds and the human voice, into musical notes. In the original system by [6], if the operator gave a start trigger, the system would initiate the processing to obtain the F0 (fundamental frequency) time series from the acoustical signals (i.e., a singing voice), which were being recorded via the microphone. The short-term F0 estimation by Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) for the power spectral is repeated until the system catches an end trigger from the operator (i.e., the caregiver) and the system then calculates a histogram of pitches with the F0 time series between the start and end triggers. Finally, only the one most frequent pitch is selected and is output as the pitch of the period.

For our research, some processing designs were modified. Figure 2 shows the processing of the system. Considering the attitude of operator, we would assume that the triggers would be input "after" the operator catches the utterance of patient. Therefore, we omitted the start trigger. The system starts a short-term F0 estimation just after invocation of the system and continues it ever since then. When the operator inputs a trigger that is regarded as an end trigger, the system calculates a representative pitch for a predetermined period just before the trigger based on the above mentioned method. Then the system plays a prepared MIDI sequence of cadences (see section 3.1) that corresponds to the representative pitch. These modifications of our system are to improve usability by reducing the time lag between the input of the trigger and the output of cadence.

To extract the F0 against the mixed acoustical signal of the patient's utterance and the cadence output from the speaker, our system needed two of the same microphone (the better solution is one stereo microphone) and one speaker. The microphones are set in front of the speaker to record the speaker's sound at the same level from both microphones. On the other hand, both microphones are displaced against the patient to record the levels of the patient's utterance that are clearly different. The system calculates the differential signals from the signals of both microphones to cancel the sounds of cadence where they are localized in the center position. The F0 estimation is then determined with these differential signals.

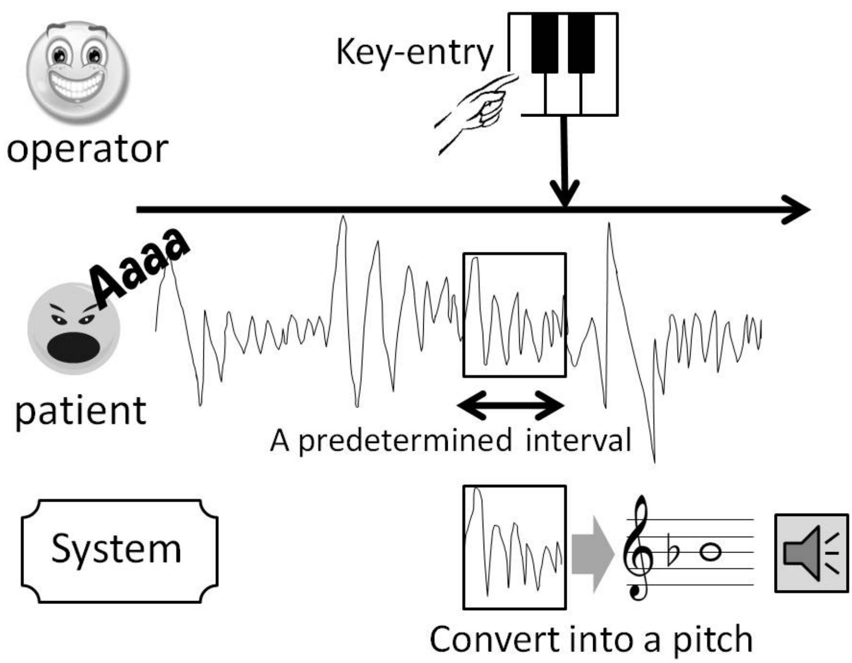

Fig. 2. Processing design for our research

3.3 Cadence Output from the System

The patients who repeat utterances have irritable moods and high anxiety in many cases. We would like to lead their emotions to calmness by performing music. What kind of music should the system output? Generally, dissonance chords indicate tension and consonance chords indicate relaxation. Clinically, a combination of these chords can elicit tension and relaxation within the human body. As a prototype system for the first step of our research, we prepared 96 cadences that begin with dissonance chords and finish with consonance, as well as terminative chord.

These cadences were picked out from two piano suites; “Das Wohltemperierte Klavier Band 1, BWV846-869” composed by J. S. Bach in 1722 and “24 Preludes and Fugues, Op.87” composed by D. D. Shostakovich in 1952. Both suites consist of 24 pieces (24 tonalities) and one piece consists of a Prelude and Fugue. We could prepare at least 96 cadences, if two cadences were chosen from one piece; the Prelude and the Fugue.

The pieces composed by Shostakovich conclude with a more agitated tone, with emotional and temperament cadences achieved through chromatic inflection, compared to those composed by Bach. Therefore, the cadences selected from the pieces composed by Shostakovich were tentatively designated “Black-type cadences (see section 3.1)” and the cadences chosen from the pieces composed by Bach were called “White-type cadences (see section 3.1)”. The operator can choose the type of cadences with a simple key entry.

The top note of the first chord in each cadence is applied as any of 12 tones, Do, Do Sharp, Re, Re Sharp, and so on. In the same way, the converted pitch is applied as any of 12 tones. In both classifications, the system ignores determination of high or low octaves of tones, tentatively in this paper. In other words, the plural cadences correspond to each of 12 tones converted from the patient’s utterance.

4 Conclusion

We presented an accompaniment system that automatically plays a cadence based on pitches converted from a patient’s voice in response to an operator’s key entry. An important technique of the system is conversion of human voice that has unstable pitches and unclear periods into musical notes. Then, a theory of combination of tension and relaxation on the music also contributes to setting up the system. Clinically, these chords can elicit tension and relaxation within the human body.

We will conduct experiments using the system at nursing homes. Then, we want to improve the system for patients with dementia and their caregivers. Results of the experiments will show whether the system is useful in healing emotions of the patients and convenient for the caregivers. Moreover, the results will clear what kind of music resonates with the patients' emotions more than the music using now.

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Human-Centric Situational Awareness in the Bedroom

Yu Chun Yen[1], Jiun-Yi Li[1], Ching Hu Lu[1,2], Tsung Han Yang[1], and Li Chen Fu[1,3]

[1] Department of Computer Science, National Taiwan University
[2] INSIGHT Center, National Taiwan University
[3] Department of Electrical Engineering, National Taiwan University
Taipei, Taiwan

Abstract. Bed-related situation monitoring is a crucial task in geriatric healthcare. Due to shortage of qualified caregivers, automatic detection of the situation in a bedroom is desirable since risks may arise when an elder gets up from the bed alone. In addition, analyzing the total amount of care time of an elder is helpful when the social effect on the improvement of the elder's health needs to be evaluated. This paper presents a context-aware healthcare system which makes use of multi-modal and un-obtrusive sensing technology meanwhile taking human feeling into account. Specifically, we choose ambient sensors such as pressure straps and a laser scanner to monitor both the activity of the elder and his/her surroundings. Moreover, a context fusion is further proposed to infer the situation of the elder. Experimental results demonstrate the high promise of our proposed methods for bed-related situation awareness.

Keyword: Context-aware, situation awareness, multi-modal sensor fusion.

1 Introduction

Situation monitoring is a crucial task when the elderly people living alone or being unsupervised. Due to shortage of the qualified caregivers, an assistive eldercare system will be helpful for alleviating the pressure from these caregivers. Evidence shows that the risk of tripping is high especially when the elder is getting out of bed [1]. Moreover, dizziness condition may be introduced when the elder sitting up on the bed from a lying position. In addition to detecting different actions on the bed, monitoring the situations in different close-by areas around the bed is also important. For instances, the total caring time of caregivers coming around may indirectly reveal the mental health of elderly people. Therefore, we propose a human-centric situational aware system which targets at detecting five on-bed and bed-side activities including *Sleeping, Sitting, Leaving Bed, Caregiver Around* and *Walking*.

In order to detect the undergoing activities of an elder, sensors are chosen and deployed according to the scenarios relevant to the activities. Generally, ambient sensors have been involved in recognizing bed-related situations in many researches [3, 4]. Such ambient sensors will bring the least disturbance to the original life of the elder when being compared with the wearable sensors. Therefore, we choose ambient sensors and deploy them to detect the activities of interest in this work so that the elder

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can proceed with those activities just like before, i.e., without any interruption. Among these ambient sensors, pressure sensors are the most inconspicuous ones since they can be laid out in any appropriate format suitable for serving as a sensing mat for bed-related activity detection. In order to make the implementation more practical, we try to lessen the sensor cost and the deployment labor while maintaining the sensing accuracy. After several pilot experiments, we finally decide to employ 11 pressure sensor straps to form the sensing mat for a single bed.

Due to the fact that a pressure mat can only detect the pressing actions performed on a bed, we further incorporate a laser scanner beneath the bed for detection purpose so as to tell whether the elder or the caregivers are around the bed. Specifically, we analyze the distance-angle readings of the laser scanner and categorize each reading into its corresponding area according to the translated coordinate of detection outside the frame of the bed. Now, in order to fuse the data from the laser scanner and the pressure sensors, a spatiotemporal Bayesian classifier serving as a high-level data fusion engine is designed to infer bed-related situations. To achieve higher accuracy of the inference task, we also take the temporal relationship among all sorts of extracted features into account.

2 Related Work

Numerous researchers have conducted bed-based sensors to analyze bed-ridden behaviors and gave automatic assistance to the elders according to the analysis. Seo [3] *et al.* proposed an Intelligent Bed Robot System (IBRS) which equipped two robot arms and a pressure sensor mattress on a special bed for assisting elderly people and the disabled. Focusing on monitoring situations of the elders around the bed, Weimin *et al.* [2] weaved 7x7 circular pressure sensors and eleven pressure sensor straps to detect the user's movement on the bed. Although they acquire good performance in classifying targeted situations of the elders, the sensor deployment is still too costly. Besides pressure sensors, they incorporated camera for sensor data fusion. Despite that the visual system can obtain rich information on human postures, the involved computational complexity is quite high and its performance is varied with the camera settings of as well as the environment (such as different view-angles of the camera and different illuminations). Moreover, the privacy issue of using a camera might be a critical concern for an elder or a patient. In the work [5], wearable sensors such as ultrasounds, RFIDs, and accelerometers were used to detect dangerous situations for the elders. However, the wearable sensors are generally considered inconvenient for practical use.

In order to propose a more human-centric smart bedroom, our work focuses on using *non-obtrusive* sensors such as pressure straps and laser scanner to recognize bed-related situations. The meaning of the term "*non-obtrusive*" refers to a description indicating that the elderly people are not disturbed both physically and mentally. These non-obtrusive sensors hereby will be deployed seamlessly in the environment and all together provide the contexts about activities performed by the elders.

3 System Architecture

In this section, we provide an overview of the proposed human-centric situational aware system. We choose *non-obtrusive* sensors with multiple modalities for the reason mentioned previously. Moreover, since sleeping and taking a rest are the major activities in a bedroom and these two activities often proceed under very low illumination, which may render the use of camera even more non-preferable. Therefore, a laser scanner or extensive floor pressure sensors will be adopted for detecting users' current locations. Given this thought about sensor arrangement, a more human-centric environment can be created.

Rather than use the received sensor's raw data directly, we hereby interpret every sensor reading as a high-level feature. Biswas *et al.* [7] defined a *micro context* as a fragment of information about one user and his/her activity related contexts. For instance, they took activity primitives as the *micro contexts*. They found that *micro context* information gives better recognition assistance than low-level sensor feature. By borrowing their concept, we therefore, define two types of *micro contexts* in our work here, namely, *bed-related micro contexts* and *location micro contexts.* Since a bed is often the major object in a bedroom, the bed-related activities will be our main focus. In this paper, *bed-related micro contexts* will be jointed with *location micro contexts* for further co-inference. The multi-modal *micro contexts* are fed into a classifier to infer the current situation. Moreover, some activities are inferred by considering the temporal relationships among various *micro contexts*, including *bed-related* and *location micro-contexts.* All these temporal features are learnt in the offline training phase and will be incorporated into our activity models.

4 Methodology and System Implementation

In this section, we introduce our system implementation. We choose pressure straps as the bed-based sensors which are attached to the mattress ticking and a laser scanner as the location awareness sensor. Next, we provide more details on how the system is implemented.

4.1 Bed-Related Micro Context Extraction

The *bed-related micro contexts* are acquired by analyzing the readings of pressure straps deployed on the bed. We use wireless sensor network nodes to receive and send sensor messages. We apply event-driven mechanism in sensory data transmission, which means the node sends out a packet only when the difference between the current and the previous readings exceeds a predefined threshold. Each received sensor reading will be converted into binary state based on a predefined threshold *T*. Both the threshold value of the difference of successive readings and the cut point for binary states converter are acquired from experiment results.

As for the process of inferring the current *bed-related micro contexts,* we first observe the primitive postures of the elder on the bed corresponding to different targeted situations. After some experiments, we found that four primitive postures will be sufficient to classify every situation we interested in. Therefore, we take each posture as one *bed-related micro context* and annotate it using one label from {*Lying on Bed, Sitting on Bed, Sitting near Right, Sitting near Left*}. Unlike most of the prior works making use of all sensors deployed on the bed to detect the current posture of the user, we segment the bed top into four meaningful regions, each of which covers a group of

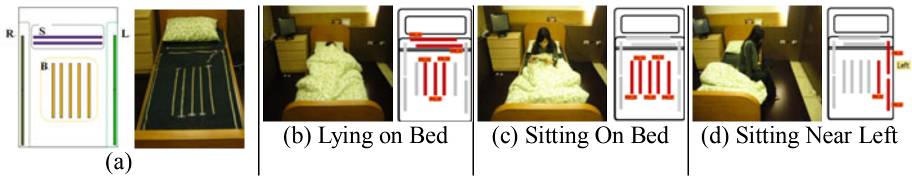


Fig. 1. Image of our bed deployment and three snapshots of pictures and their corresponding monitoring interface

pressure sensors. These regions are namely ***R**-Right Side,* ***S**-Shoulder Part,* ***B**-Lumbar-Hip Part, and* ***L**-Left Side,* and each group of pressure sensors takes charge of providing some *bed-related micro contexts*. Note that the ***R**-Right Side* sensor group and the ***L**-Left Side* sensor group are deployed to detect whether the user is sitting near the long bed edges, whereas the sensor group over the ***S**-Shoulder region* is crucial for the detection of "*Lying on Bed*" posture since empirical evidence indicates strong correlation between the nontrivial shoulder pressure and the "lying down" posture. In ***B**-Lumbar-Hip region*, we put five pressure sensor straps, all separated by some distance and laid out in parallel to the long bed edges, mainly in the proximity of the bed's middle so that we can reason the direction the user is moving in laterally by analyzing the state changes over the five pressure straps. Figure 1(a) shows the layout of our pressure straps deployment.

Table 1. Partitioned rule-based bed-related micro context inference mechanism

Bed-related Micro Context Processing algorithm
Initialize L_n, S_n, B_n, and R_n to 0.
Initialize all *part vectors* to default condition (each element is in "*Off*" state).
while a new *event vector* is received
Update the corresponding *part vector* according to the pressure ID of the *event vector*
Recalculate and update *part vector*
if $S_n > 0$ ***and*** $B_n > 1$
micro-context := *Lying on Bed*
else if $S_n = 0$ ***and*** $B_n > 1$
micro-context := *Sitting on Bed*
else if $S_n = 0$ ***and*** $B_n < 4$ ***and*** $R_n > 0$ ***and*** $L_n = 0$
micro-context := *Sitting near Right*
else if $S_n = 0$ ***and*** $B_n < 4$ ***and*** $L_n > 0$ ***and*** $R_n = 0$
micro-context := *Sitting near Left*
end while

Two types of feature vectors for the pressure sensors are used in the system. The first type is an *event vector* which contains only the currently received pressure strap ID and its converted binary state. The other type is a *part vector* which contains all pressure states of the sensor group covered by one region (Refer to Fig. 1(a)). The *part vectors* will continually update states over time. As mentioned, we create a *part vector* for the group of pressure sensor straps for every region. For instance, the *part vector B* at time *t-1* is {*On, On, Off, Off, Off*}. If the leftmost sensor of part *B* is changed to "*Off*" at time *t,* then the *part vector B* will be updated to {*Off, On, Off, Off, Off*} at time *t*. Thus, the system can forward all the most up-to-date *part vectors* into a *partitioned rule-based inference mechanism* to infer the *bed-related micro contexts* using the algorithm shown in Table 1. There are four variables L_n, S_n, B_n, *and* R_n indicating the respective numbers of the pressed sensor straps within the sensor group covered by respective regions.

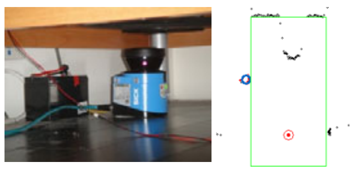
4.2 Location Micro Context Extraction

The source of a *location micro context* originates from the laser scanner. The LRF is placed on the floor beneath the bed closer to the headboard. Figure 2(a) shows the arrangement of the laser scanner used in this work. The blue circle in Fig. 2(b) points out the possible coordinates of a possible caregiver nearby the bed.

In order to track the caregivers around the bed and distinguish their movement paths, we further translate the possible users' coordinates into *location micro contexts* based on their distances vs. their nearest bed edge. In preliminary phase, we simply segment the area around the bed into six sub-regions as shown in Fig. 3. For location estimation, we use the Cartesian coordinate system and set the laser position as its origin represented as a red circle in Fig. 3. Different sub-regions have different distances to the bed. Experimental tests indicate that the mean distance between a caregiver and the bed edge is within 1 m; besides, we observe that the caregivers are accustomed to stand in the two sides of the bed rather at the tail of the bed, which reminds us that we should segment area nearby the tail of the bed into another sub-region. With all these segmented sub-regions, a *location micro context* can be represented by an *area label*. A sequence of *area labels* reveals the temporal path of a caregiver or the elder. For example, a caregiver approaching the bed may lead to the *area label* sequence {R_2, R_1}, whereas the other sequence such as {R_1, R_2} may imply the activity of a user, elder or caregiver, is leaving from the bed.

4.3 Temporal Feature Handling and Situation Awareness

After gathering *bed-related micro contexts* and *location micro contexts*, we then fuse these two micro contexts to infer if one of the five targeted bed-related situations occurs. First, we learn the temporal features from training data for each situation. We run *Temporal Feature Test* for each situation which automatically finds whether a situation contains *n-gram temporal features* from the training data. In this work, we prefer to use *two-gram temporal feature* for problem simplification. That is, a *two-gram temporal feature* is composed of successive state changes of two different *micro-context*s within a specified time window for the same situation. Take the {*Leaving*} situation as an example. One may shift one's center of gravity from the bed's middle towards one side of the bed, and then put his/her feet down on the ground. In such case, the *Temporal Feature Test* will find two two-gram *temporal features* which are {*Sitting on Bed*$\rightarrow$*Sitting near Right*} and {*Sitting near Right*$\rightarrow$*R1*}. Since we adopt the event-driven data transmission strategy, the time window for detecting a temporal feature is defined by the number of state changes rather than by the interval of the time window. We predefine the length of time window *W* to test whether there exists any temporal feature in a situation. If two successive state changes of different



(a) (b)

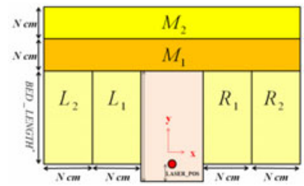


Fig. 2. (a) Laser Range Finder put under the bed. (b) Candidate human detected

Fig. 3. The sub-regions of the area around the bed (N=100 in our work)

micro contexts occur within the predefined time window, we combine the two *micro contexts* and introduce a new *temporal feature* for that situation. After composing temporal features for each situation, we apply WEKA [9], an open-source Data Mining Software in Java, to build five Bayesian Network models, each of which represents one situation of interest. Before the model training, we pool training data into the Attribute Selector (also supported by WEKA) which runs the Best First search algorithm to choose all relevant features corresponding to each situation. After selecting the relevant feature sets, we build up five independent Bayesian models, one for each situation, based on the chosen features. The five models will be further used in testing phase to infer the current situation. The feature set obtained in testing phase is expressed as $f_t = \{BM_t, LM_t, TF_{\sim t}\}$ where BM_t is the *bed-related micro contexts* inferred at time t and LM_t represents the interpreted *location micro contexts; $TF_{\sim t}$* is temporal feature sets composed within the interval [t-W, t] where W is the predefined time window. We take f as observation and feed it into the trained Bayesian models corresponding to each interested situations. After calculating the probability of each model given f, the situation whose probability exceeds the threshold value will then be regarded as the one which is taking place at time t.

5 Experiments and Results

We run a pilot experiment in NTU INSIGHT OpenLab, an experimental space aiming to support research on smart home. Three participants are recruited to test the feasibility of the work; one is female and the other two are males. Their heights range from 160 to 183 cm and the weights ranging from 47 to 63 kg, respectively. The bed size is 200cm ×66cm and the pressure strap is 62 cm long. All sensor signals are wirelessly transmitted. Though there is significant difference between heights of the three participants, the pressure straps put under the shoulder part can detect almost every "lying down" action. The evaluation of our *bed-related micro context* is shown in Table 2. The confusion matrix shows the high accuracy rate in each *bed-related micro context*. Some misclassifications occur when the participant sits in the middle of the bed but put his/her hands near the pillow. The hands may trigger the *Shoulder Part* pressure sensors and mislead S_n to become a positive number. Consequently, *Sitting on Bed* will be misclassified as *Lying on Bed*.

Table 2. Confusion matrix for bed-related micro context inference

		Detected bed-related micro context			
		Lying on Bed	*Sitting on Bed*	*Sitting near Right*	*Sitting near Left*
Ground Truth	*Lying on Bed*	100%	0%	0%	0%
	Sitting on Bed	5%	94.3%	0.4%	0.3.%
	Sitting near Right	0%	14.6%	85.4%	0%
	Sitting near Left	0%	9.3%	0%	90.7%

Table 3. Detection accuracy for five situations

	Sleeping	Sitting	Caregiver Around	Leaving	Walking
Precision	91%	99.2%	98%	97%	100%
Recall	100%	95.6%	85%	89%	81%

Another misclassification occurs when *Sitting on Bed* is falsely identified as *Sitting near Right/Left*. Such misclassification is caused by the structure of the bed. The distance from the top of bed to the ground is only about 35 cm, but the shank length of our tallest participant's is about 45 cm. Therefore, all of the *Right/Left Side* pressure sensors will not be triggered when this participant sits near either side of the bed. It violates our rules of R_n >0 or L_n >0 and make the final classification as *Sitting on Bed*. This motivates us to establish more user-independent rules to increase the overall robustness. With the *bed-related micro contexts*, we next derive the *location micro contexts* from the laser scanner, and then run *Temporal Feature Test* to find temporal features for every situation. After composing temporal features by analyzing the training data, we train Bayesian models offline for each situation and apply the Attribute Selection in WEKA. The experimental result is shown in Table 3. For situations *Sleeping*, *Sitting*, *Caregiver Around*, and *Walking*, precision and recall are calculated based on every feature set f defined in section 4.3. For the situation {*Leaving*}, it is difficult to define the starting point of the "*leaving bed*" activity. Therefore, we define a true positive as successful detection of the event where a user completes the entire leaving bed activity. From the result, precision of {*Sleeping*} is influenced by the {*Caregiver Around*} because the laser scanner missed some information of the caregiver. We analyze potential disturbance and found out that the structure of our currently selected bed limits the detection ability of the laser scanner for the reason that the lowest frame of the current bed is not 40 cm high, which is the least height for normal leg detection using laser scanner according to our prior work [6].The situation {*Sitting*} will be confused with the situation {*Sleeping*} if the user put his/her hands near the pillow.

7 Conclusion and Future Work

In the paper, a multi-modal sensing and high-level context fusion strategy are proposed to detect bed-related situations. We choose pressure sensor straps and a Laser Range

Finder (also known as a laser scanner) to monitor the activities in the bedroom environment. We employ totally eleven pressure sensor straps rather than a uniform pressure sensor array and categorize them into four groups, each being responsible for extracting features for one region of the bed top. Therefore, the pressure sensor readings of different sensor groups provides not only the sensor states covering different regions of the bed but also the positional information related to user's activity on the bed. In addition, the usage of the Laser Range Finder provides reliable information about people around the bed even under very low illumination. By fusing the two types of information appropriately, we can hereby infer one of the five situations {*Sleeping, Sitting, Caregiver Around, Leaving*, *Walking*} reliably. Experimental results have confirmed the effectiveness of our proposed system, which makes our system especially feasible for an elder staying in a bedroom environment. Our on-going work is to improve the recall rate by analyzing more detailed information based on readings of the eleven pressure straps and/or by rearranging the place of the laser scanner. In addition, human path tracking will be taken into account using the laser's detection technique.

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A Subarea Mapping Approach for Indoor Localization

Shumei Zhang, Paul McCullagh, Chris Nugent, Huiru Zheng, and Norman Black

School of Computing and Mathematics, University of Ulster, BT37 0QB, U.K.
{zhang-s2,pj.mccullagh,cd.nugent,h.zheng,nd.black}@ulster.ac.uk

Abstract. Location information can be useful to construct a profile of a person's activities of daily living. This paper proposes an approach with the aim of improving the accuracy and robustness of a location recognition approach based on RFID technology. A method was introduced for the optimal deployment of an RFID reader network, which aims to minimize the hardware cost whilst achieving high localization accuracy. A functional subarea mapping approach was proposed based on both a coarse-grained and a fine-grained method. Experimental results indicated that the coarse-grained mapping provided a higher overall accuracy of location detection. The average subarea location accuracy achieved based on coarse-grained and fine-grained data was 85.4% and 68.7%, respectively. Nevertheless it was found that the fine-grained mapping approach was capable of providing more information in relation to the details of the functional subareas. This implies that we need to balance the requirements between the size of the subareas and the location accuracy.

Keywords: subarea mapping; localization; RFID; optimal deployment; smart homes.

1 Introduction

Location information provides useful contextual related details. Within the realms of smart environments location based information is widely used in the ubiquitous computing elements which support ambient assisted living (AAL) applications. Global positioning systems (GPS), which are based on satellite surveillance, can be used for the purposes of outdoor localization. Indoor location tracking systems vary widely in their technology platform, accuracy, locating range and infrastructure costs. Wireless sensor networks (WSNs) have gained much interest in location-aware applications [1]. Their advantages include low cost, small size and easy mobility all of which provide opportunities for monitoring, tracking, or controlling applications, such as environment monitoring, object tracking, health monitoring and fire detection. A number of wireless technologies have been exploited for indoor localization with varying degrees of advantages and disadvantages. A comparative study by Ni [2] revealed that Radio Frequency Identification (RFID) was a competitive technology for indoor location sensing.

The aim of this study has been to develop an indoor location detection system for use in a context-aware application within the remit of an AAL based application. Our

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objectives were to design an optimal WSN deployment and to develop robust location tracking algorithms with the anticipated effect of improving localization accuracy using RFID technology.

The remainder of the paper is structured as follows. In Section 2, related work in the field of WSNs is discussed. Methodologies for deployment of the RFID system and the location detection algorithms are explained in Section 3. Section 4 is focused on the location classification experiments and presents the experimental results. Finally, the Discussion and Future Work is presented in Section 5.

2 Related Work

Indoor location-sensing techniques include infra-red (IR), ultrasound, radio frequency (RF), Wi-Fi, ultra wide band (UWB), and Bluetooth [3]. Nevertheless, the challenge of how to minimize the deployment and infrastructure costs whilst still maintaining a precise indoor location tracking service still remains an open research problem [4].

'Active Bat' [5] is a location-aware system which installed two base stations and 100 ultrasound receivers within two rooms. The system calculated the corresponding Bat-receiver distances according to the incoming ultrasound time-of-arrival. The position accuracy illustrated that 95% of readings were within 9cm of their true positions. In general, techniques based on ultrasonic location have been shown to provide accurate location based information to accuracy levels in the region of centimeters. Nevertheless, it is expensive requiring up to 15 receivers for each single position calculation. Bahl *et al.* [6] presented an RF based building-wide location tracking system referred to as RADAR. They placed three base stations in a floor area of 980 sq. m. During experimentations a user carried a laptop which acted as a mobile host. The station and mobile host communication was based on the IEEE 802.11 technology. The signal strength recorded during the experiments was used to calculate the 2D position using a nearest neighbor algorithm (kNN). Their location accuracy was in the range of 2 to 3 meters. The advantage of the RADAR system was that it only required a few base stations for coverage of the whole floor. Nevertheless as the mobile host must support a wireless LAN interface, it may be potentially impractical in some cases.

Ni *et al.* [2] presented a location identification method based on a dynamic RFID calibration (LANDMARC) approach which employed fixed reference tags serving as reference points to assist location calibration. They used Euclidean distance measured by the RSS (received signal strength) with k-NN algorithms to find the tracking tags' nearest neighbors. The distance is measured between the reference tags and the tracking tag. They highlighted that the granularity and localization accuracy were affected by three key issues: (1) placement of the reference tags, (2) the number of the reference tags, and (3) the definition of the weights which were assigned to different neighbors. LANDMARC deployed one reference tag per square meter to accurately locate the objects within an average error distance of 1 meter. The outcome of the study concluded that the RFID technologies were cost-effective and competitive for the purposes of indoor location detection. Hallberg *et al.* [7] proposed an approach for localization of forgotten items as an alternative to the LANDMARC approach. The results attained within the study demonstrated improved accuracy with a reduced number of reference tags.

This study aims to detect a person's position within a smart home environment. In the home environment, there may be many people moving around, hence using RFID technology is a good solution to detect the location, along with identifying exactly 'who' is in the location. Nevertheless, the RF signal may be occasionally lost. The challenges of location detection based on RFID technology are: (1) how to deploy an optimal RFID system that is low-cost and maintaining reasonable localization accuracy; (2) what algorithms to use to improve the localization accuracy and computational efficiency compared with related works; (3) how to assess and accommodate for the missing RF signal data.

3 Methodology

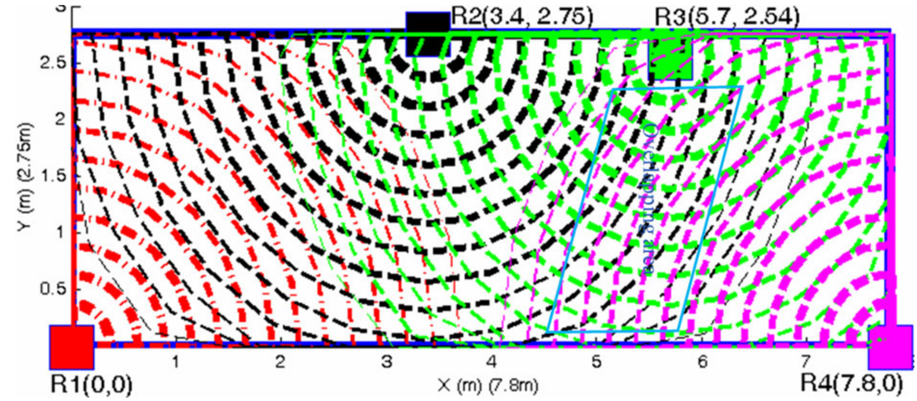
In our studies, the experimental environment is a simulated smart home which consists of two rooms [8]. One room is configured as a kitchen, the other as a living room. The combined size of the two rooms is 8.86m by 3.76m. Taking into consideration the furniture within the rooms, the active area is 7.8m by 2.75 m.

Two common problems should be considered when deploying an RFID system. Firstly, reader collision occurs in the area where the signals from two or more readers overlap, since the tag cannot respond to simultaneous queries. Secondly, tag collisions occur when many tags are present in a small area [9]. Inappropriate layout of readers can therefore be deemed to compromise the performance of the RFID system.

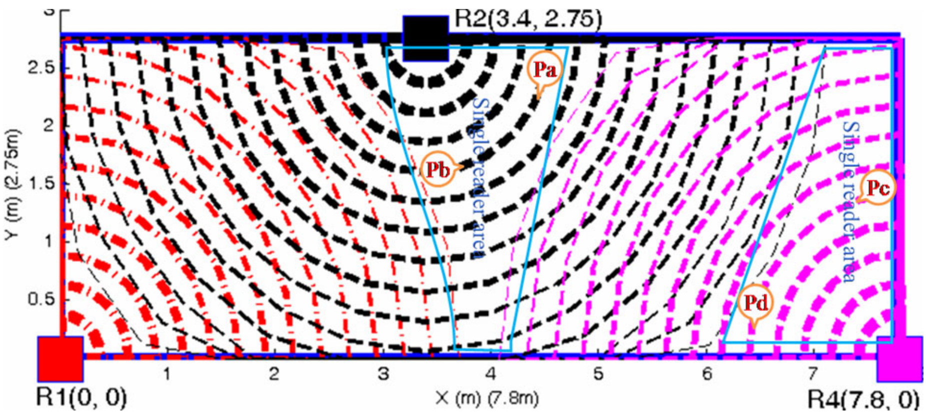
3.1 Method for Optimal Deployment of RFID System

In this study, we used the Adage RFID products, Dyname Readers and Carme Active tags [10]. The RFID reader/active tag frequency is 868MHz. The optimal detection range is up to 8m. The measured readable range in our experiments was in the region of 4.5m with a robust range in the region of 4 meters. Each RFID tag is pre-programmed with a unique 6 character identification (ID).

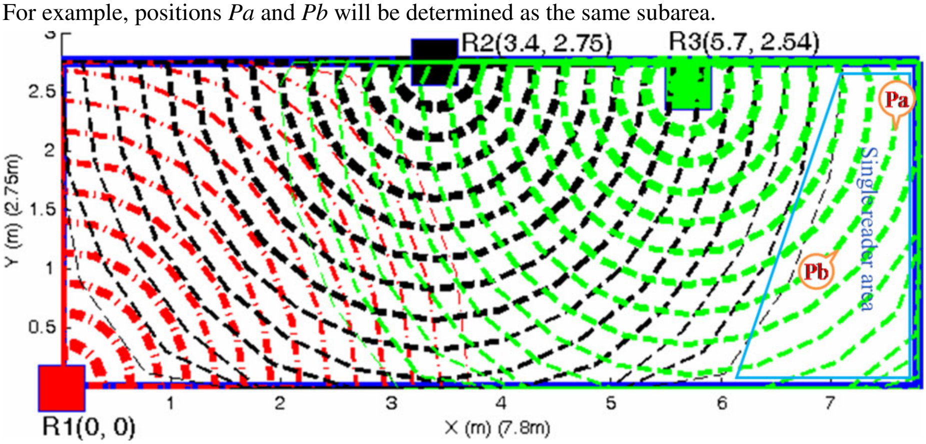
In theory, the RF signal is reduced in strength as a function of the distance from the reader. Each reader can cover a maximum circular region around itself, the radius of which is within the stable distance of 4 meters for our devices as previously explained. In the first instance, seven possible deployments were designed based on RF propagation theory. The reader numbers were varied from 2 to 4 and also their position within the environment was also varied. Based on these experiments we selected three deployments from the seven considered according to the visual analysis results as shown in Figure 1 (a), (b) and (c). The visual analysis involved inspecting the figures for the following regions: that of least overlapping coverage by multiple readers, or fewest indeterminate positions where only covered by a single reader. The three deployments were referred to as *R1234*, *R124* and *R123*. Each *reader* (R_1, R_2, R_3, or R_4) covered a region within the tracking environment, according to its position.



(a) *R1234* deployment. Overlapping region identified with a solid rectangle.



(b) *R124* deployment. Two indeterminable regions identified with the solid trapezoid. For example, positions *Pa* and *Pb* will be determined as the same subarea.



(c) *R123*: deployment using three readers. One indeterminable region identified with a solid trapezoid. For example, position *Pa* and *Pb* can be determined as the same subarea.

Fig. 1. The three preferred deployments of a fixed *reader* network selected from seven possible schemes. The corresponding position of the *readers* is shown in each of these figures (a), (b) and (c).

With the deployment *R1234*, the active area was covered well. Nevertheless, there is one area which was overlapped by the three readers and has been identified using a solid rectangle as shown in Figure 1 (a). This has the potential to increase the risk of reader collision. With the deployment *R124*, coverage is sufficient with a lesser reader overlap. Nevertheless, there are two areas which were covered by a single reader as shown in Figure 1 (b). These areas could be compromised due to indeterminate subareas. For example, positions *Pa* and *Pb* or *Pc* and *Pd* will be determined as the same subarea, since they are in the same circle and relative to a single reader. Hence, the RF signal strength (R_{SS}) value obtained from *Pa* and *Pb* or *Pc* and *Pd* are the same. With the deployment *R123*, most of the areas can be covered by two readers, only one area is have the potential to be indeterminate, which was covered by a single reader as shown in Figure 1 (c). Following the graphical analysis above, the *R123* deployment was determined as the preferred reader network for our smart home environment experiments.

3.2 Subarea Mapping Approach

We proposed a subarea mapping approach for indoor location detection. The subareas were divided according to their functions. The concept is based on an RF signal strength (R_{SS}) distribution model related to the subarea structured environment being learnt based on a training set. The training set was collected from a mobile *tag* carried by a person moving throughout the environment. The resulting R_{SS} subarea distribution model was used to map the sensed R_{SS} from an unknown mobile tag into a functional subarea defined during the training stage. The advantages of this approach are that with the final deployment of the location based system there is no requirement for the RF signal propagation model and also does not require the distribution of many reference tags.

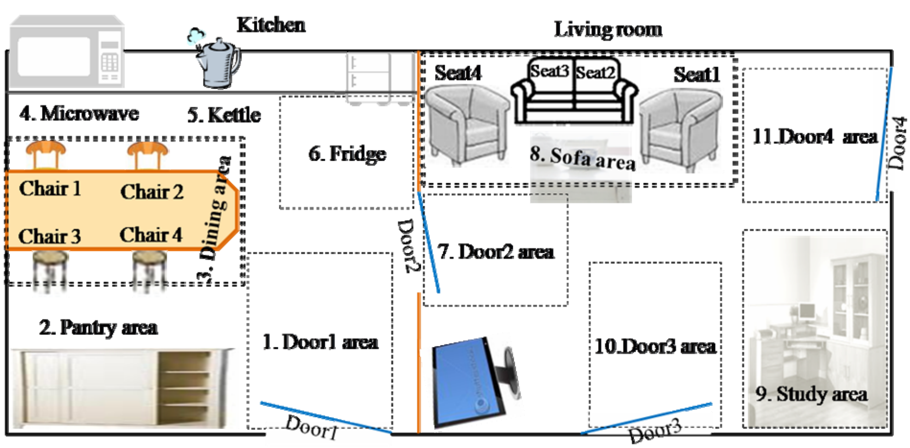


Fig. 2. The smart home environment. The left side of the diagram depicts the kitchen area and the right side depicts the living room area.

The tracking environment is divided into several functional subareas based on the inhabitant's likely activity of daily living (ADL). In order to assess the relationship between the size of the subareas and the accuracy of location detection, we categorized the subareas in two levels: a fine-grained level and a coarse-grained level. Using the coarse-grained categorization, 11 subareas were specified according to the primary function. Using the fine-grained categorization, the Dining and Sofa areas (subarea number 3 and 8 in Figure 2) were further divided into smaller subareas such as chair1, chair2, chair3, chair4, seat1, seat2, seat3 and seat4. In this way, a total of 17 subareas were specified.

The subarea learning and mapping approach can be described by the following two phase process: offline learning and online localization.

1. Offline learning

The R_{SS} sensed by the reader network *R123* and the subarea structure of the environment (E) are symbolized as presented in Equation 1:

$$R_{SS} = \bigcup_{r=1}^{3} R_{SSr}; E = \bigcup_{j=1}^{m} L_j, m = \begin{cases} 11 & coarse-grained \\ 17 & fine-grained \end{cases} \quad (1)$$

Where $R_{SSr}, r = 1,2,3$ represents the RF signal strength sensed by each of the readers R_1, R_2 and R_3; $L_j, j = 1,2,\cdots,m$ denotes the location name of each of the subareas.

The collected training set from each of the subareas is organized as a format as presented in Equation 2:

$$(R_{SS}(i), L(i)) = (R_{SS1}(i), R_{SS2(i)}, R_{SS3}(i), L(i)) \quad \{i = 1,\cdots,n\} \quad (2)$$

Where n is the total number of samples in the training set; $R_{ss}(i)$ is the set of signal strengths sensed by three readers at the *ith* training point; *L(i)* is a manually labeled subareas' name for the *ith* training point; $L(i) \in E(L_1,\cdots,L_m)$ and m is the total number of subareas.

Following this a function (training model) $f(R_{SS}, E)$ for the relationship between the R_{SS} and each of the subareas in the tracking environment E is learned by a classifier algorithm from the training set.

2. Online localization

After the function has been obtained during the offline learning, it can be used to classify a tagged subject's location online. In the test phase, the sensed R_{SS} union at each time t is an input value of the function. The output at the each time t is a subarea name automatically translated from the input value by the function $f(R_{SS}, E)$.

4 Experiments

Following collection of the training and testing data respectively, the experimental results were compared in two different manners: fine-grained versus coarse-grained methods. With the intention of imitating the natural dynamic human ADLs, the tracking tag was worn by the inhabitant rather than using static reference tags.

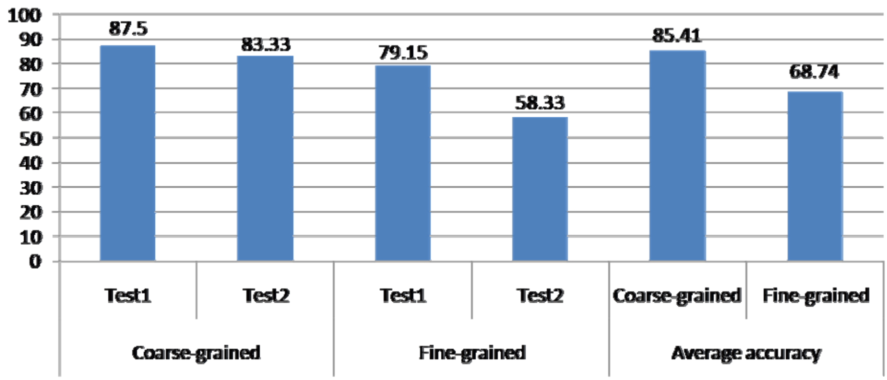


Fig. 3. Comparison of the accuracy between single mobile tag and multiple mobile tags, in addition to fine-grained and coarse-grained localization levels using the SVM classifier. *Test1* data set was collected using a single mobile tag (one person); *Test2* data set was collected using three mobile tags carried by three inhabitants concurrently.

During collection of the training data, each of three subjects was asked to walk around all 17 subareas and to stand or sit in each of the three boundaries for one minute for each subarea. The inactive period of time was designed for one minute to guarantee at least two data repetitions for each position (RFID sensing frequency is in the region of 24seconds for each of the three readers). The training data collected were subsequently pre-processed firstly to correct the missing data [11]. Following this the corrected training data were saved as two groups (trainFine and trainCoarse). The two training data sets were used to train two models, to compare the effect of the size of the subareas on the performance of location classification.

The testing data were collected in two experiments, *Test1* data set was collected from the 17 subareas by one tagged person; *Test2* data set was collected from subareas by three tagged inhabitants concurrently. Each experiment was repeated three times by subjects following natural behavior i.e. there was no limitation on their position or the direction in which they faced, although it was known that their positions or rotations could influence the RF signal strength values. The data sets were classified using LibSVM (support vector machine) classifier [12] and compared from two different aspects: (1) single mobile tag vs. multiple mobile tags; (2) coarse-grained vs. fine-grained. The experimental results are presented in Figure 3. The experimental results show that the *Test1* and *Test2* obtained similar accuracy (87.5% vs. 83.33%) for coarse-grained localization level. Nevertheless, *Test1* obtained a higher accuracy than *Test2* (79.15% vs. 58.33) for the fine-grained localization level.

5 Discussion and Future Work

An accurate and robust location detection approach is important for location-aware applications. This study proposed solutions to improve the location recognition accuracy within RFID based systems. Initially, we analyzed how to design an optimal deployment of an RFID reader network. An appropriate RFID system should minimize deployment infrastructure costs whilst maintaining acceptable levels of location accuracy. Subsequently, a subarea mapping algorithm was evaluated using fine-grained and coarse-grained localization levels. In theory, it is expected that the coarse-grained method can achieve a higher accuracy than the fine-grained method. Nevertheless, the fine-grained localization level has the ability to supply more details in relation to the functional subareas at the cost of the precision of the subarea location. We therefore need to balance the requirements between the size of functional subareas and location accuracy for real applications. The average subarea location accuracy based on coarse-grained and fine-grained data following our experiments was 85.4% vs. 68.7%, respectively.

A number of the studies proposed use the reference tag approach for location detection [2]. In our approach, the subarea positions were represented in a training model. This approach does not require deploying a large number of reference tags and also does not calculate the relationships between the tracking tag and reference tags. Thus, the subarea mapping approach has the potential to reduce the calculation errors and improve the localization accuracy. In addition, in our experiments, the tracking tag was carried by a person who moved randomly around the subareas. In this case, the tracking tag position changes randomly as it moves with the person. This provides a greater challenge than using a stationary tag.

Future work will aim to evaluate and improve the algorithms through the experiments performed in real activities of daily life with the goal of enhancing the algorithms to detect location for real-time applications.

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Joint Active Queue Management and Congestion Control Protocol for Healthcare Applications in Wireless Body Sensor Networks

Nazbanoo Farzaneh and Mohammad Hossein Yaghmaee

Ferdowsi University of Mashhad, Iran
Farzaneh@stu-mail.um.ac.ir, yaghmaee@ieee.org

Abstract. Wireless Body Sensor Network (WBSN) consists of a large number of distributed sensor nodes. Wireless sensor networks are offering the next evolution in biometrics and healthcare monitoring applications. The present paper proposes a congestion control protocol based on the learning automata which prevents the congestion by controlling the source rate. Furthermore, a new active queue management mechanism is developed. The main objective of the proposed active queue management mechanism is to control and manage the entry of each packet to sensor nodes based on learning automata. The proposed system is able to discriminate different physiological signals and assign them different priorities. Thus, it would be possible to provide better quality of service for transmitting highly important vital signs. The simulation results confirm that the proposed protocol improves system throughput and reduces delay and packet dropping.

Keywords: Active Queue Management; Congestion Control; Learning Automata; Transport protocol; Wireless Body Sensor Network.

1 Introduction

Wireless Body Sensor Networks (WBSNs) are a specific category of wireless sensor networks intended to operate in a pervasive manner for on-body applications [1]. The wireless body sensor network plays an important role for healthcare monitoring applications. For these applications, it is essential to be able to reliably collect physiological readings from humans via body sensor networks. Such networks could benefit from Quality of Service (QoS) mechanisms that support prioritized data streams, especially when the channel is impaired by interference or fading [2]. Congestion is an essential problem in wireless sensor networks. It not only wastes the scarce energy due to a large number of retransmissions and packet drops, but also hampers the event detection reliability.

This paper addresses the problem of congestion control in wireless body sensor networks. In this paper, a new queue management and adaptive source rate adjustment mechanism base on learning automata [3] for congestion control is proposed. The rest of this paper is organized as follows. In section 2 we present a review of related researches in transport protocols in WSN. The proposed protocol is explained In section 3. Section 4 evaluates proposed mechanism. We conclude the paper in section 5.

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2 Related Works

The study of transport protocol in WSNs has been the subject of extensive research. In [4] a priority based rate and congestion control protocol for wireless multimedia sensor networks is presented. It consists of two major units. The *Congestion Control Unit* determines the congestion intensity by calculating the difference between the input and the output rate. The *Service Differentiation Unit* supports different QoS for different traffic classes. The RCRT [5] protocol uses the length of retransmission list as the indicator of congestion. The RCRT protocol uses its rate allocation component to assign rates to each flow in keeping with a rate allocation policy. RCRT boasts a NACK based end-to-end loss recovery scheme. In [6] a novel congestion control protocol for vital signs monitoring in wireless biomedical sensor networks is proposed. Based on the current congestion degree and the priority of its child nodes, the parent node dynamically computes and allocates the transmission rate for each of its children. LACAS [7] is Learning Automata-Based Congestion Avoidance Scheme for healthcare wireless sensor networks. In LACAS there is an automaton in every intermediate node which regulates the node's incoming rate for controlling congestion locally in that node. The automaton has five actions which are based on the rate with which an intermediate sensor node receives the packets from the source node. The rate of flow of data into a node for which there is the least number of packets dropped is considered to be the most optimal action.

3 Proposed Model

In WBSN sensors are attached to different patients. Each sensor is used to monitor a vital sign. Evidently, in such life-critical applications involving a large number of patients, congestion is extremely undesirable.

In this section we explain the proposed model in details. The proposed model consists of two different parts: **1)** a learning and priority based AQM protocol and **2)** a learning automata based transport protocol. For simplicity, we name the proposed model as LACCP (Learning Automata based Congestion Control Protocol). In the current study we consider two different classes, namely *Critical* and *Normal*. *Critical* class is dedicated to loss and delay intolerant traffics while *Normal* class is assigned to other traffics. In the following subsections, we describe these two parts in details.

3-1 AQM Mechanism in Intermediate Nodes

It is clear that when the packet arrival rate is more than departure rate, the node’s queue will be filled. This, in turn, causes increased packet loss and delays. In a healthcare application, if a patient is known to have a special need, it would be possible to assign more priority to data transmitted from such a patient. In the proposed AQM protocol a packet is entered to the node's queue, based on its traffic class (Critical or Normal).

We use learning automata in order to adjust the packet arrival rate. In each intermediate node, there is a variable automaton which is shown by {A, B, P, T} where A is a set four actions as follows:

A = { *arrival_rate_incerase, no_change , arrival_rate_decrease_smoothly, arrival_rate_decrease_suddenly* }. *B* includes the set of inputs and *P* is the probability vector of the four automata actions. *P(n+1) = T[a(n),B(n),P(n)]* is the learning automata where *n* is the stage number. Table 1 gives a summarized definition of the four automata actions. Every automaton after selecting proper action receives feedback from the environment (in this paper the network). Based on the action, the transmission rate could be increased or decreased. The intermediate nodes' learning automata adjusts the transmission rate based on the *number of packets in the queue* and the *number of lost packets*. These two parameters provide a good assessment of the automata performance.

Table 1. Automaton actions in the intermediate nodes

Action name	Description
No change	The network has reached stability and there is no need to change the arrival rate.
Arrival rate increase	Since network feedback indicates small queue size and channel load, the node can increase arrival rate in order to improve throughput
Arrival rate decrease smoothly	Congestion is likely to occur or low density congestion has occurred. Therefore, packet arrival rate is decreased smoothly in order to avoid queue saturation.
Arrival rate decrease suddenly	Since congestion has occurred packet arrival rate is decreased quickly in order to avoid packet loss and queue saturation.

Let $\Delta L(t)$ and $L(t)$ show the loss variation and loss rate in time *t*. The learning automata placed in each node calculates $\Delta L(t)$ and $\Delta Q(t)$ as follows:

$$\begin{aligned} \Delta L(t) &= L(t) - L(t-1), \\ \Delta Q(t) &= Q(t) - Q(t-1) \end{aligned} \tag{1}$$

Where *L(t-1)* is the loss rate at time *t-1*. $\Delta Q(t)$ and $Q(t)$ are queue length variation and queue length at time *t,* respectively. Q(t-1) is the value of queue length at time *t-1*. Network status can be determined based on the values of ΔL and ΔQ. Different values of ΔL and ΔQ have different meanings and interpretations. For example when $\Delta L < 0$ or $\Delta L > 0$ this means that the packet loss rate has been decreased or increased, respectively. ΔL defines the amount of decrease or increase in loss rate.

After choosing an action, the automata rewards or penalizes it based on network feedback as follows:

- If $(\Delta Q(t) << 0 \; and \; \Delta L(t) <= 0)$ OR $(\Delta Q(t) >> 0 \; and \; \Delta L(t) < 0)$ the automaton is rewarded according to equation (2)
- If $(\Delta Q(t) >> 0 \; and \; \Delta L(t) > 0)$ OR $(\Delta Q(t) << 0 \; and \; \Delta L(t) > 0 \; and \; arrival\_rate << initial\_rate)$ the automaton is penalized according to equation (3)

$$\begin{aligned} P_i(n+1) &= P_i(n) + a[1 - P_i(n)] \\ P_j(n+1) &= (1-a)P_j(n) \quad \forall j \;\; j \neq i \end{aligned} \tag{2}$$

$$P_i(n+1) = (1 - b)P_i(n)$$
$$P_j(n+1) = (b / r - 1) + (1 - a)P_j(n) \quad \forall j \; j \neq i \tag{3}$$

In the above equations, ***"a"*** is the reward and ***"b"*** is the punishment parameter.

Shorter node's queue lengths lead to shorter packet waiting time for receiving service. Although decreasing packet arrival rate decreases queue length, it also increases the number of lost packets (packets which are lost due to low arrival rate) and decreases throughput. Therefore, the automaton has to strike a balance between queue length and network throughput. The number of lost packets will be increased if despite the changing of channel load, packet arrival rate remains constant. Therefore, an increase in packet loss indicates a lack of correspondence between arrival rate and the actual packet reception rate (channel load). Although the arrival rate should be decreased as queue length nears saturation, with the decrease of network throughput and queue length the arrival rate will be increased again. An increase in the number of lost packets causes the automata in the sink to decrease source transmission rate in order to decrease congestion and increase network throughput. Therefore, corporation between the automata placed in the intermediate nodes and the sink will decrease congestion.

Despite to LACAS the values of "***a"*** and ***"b"*** in equations 2 and 3 are not constant and defined based on congestion level. Thus various congestion levels have different effect on automata. Although at the beginning of operation all probabilities P_i are equal, as time passes the reward and punishment mechanism explained above will change these probabilities. Each node has two different arrival rates, namely *Critical rate* and *Normal rate*. The following relation is always true*:*

$$node\ arrival\ rate \ = Critical\ rate \ + \ Normal\ rate \tag{4}$$

Thus if the number of received critical packets increase the number of normal arrival rate is decreased. The Critical and Normal rates are calculated as follows:

$$\begin{aligned} & arrive_t = w_c \ arrive_c + w_n \ arrive_n; \qquad w_c \leq w_n \\ & \Pr ate_c = w_c \ arrive_c / arrive_t \qquad , \Pr ate_n = w_n \ arrive_n / \ arrive_t \\ & Critical \quad rate = \Pr ate_c * \ rate \qquad , \ Normal \quad rate = \Pr ate_n * \ rate \end{aligned} \tag{5}$$

where $arrive_t$, $arrive_c$ and $arrive_n$ are total received packets, total received Critical packets and total received Normal packets per time, respectively. W_c and w_n are the priority weights of *Critical* and *Normal* packets*,* respectively.

A weighted fair queue (WFQ) scheduler is used to schedule the incoming packets. To provide better quality of service for high priority traffic classes, the assigned weights used in the WFQ scheduler follows this rule: *Critical Class has higher priority*.

3.2 Congestion Control in the Sink

In addition to AQM mechanism which is placed in the intermediate nodes, in order to control and prevent congestion we need to adjust the source rate based on the congestion level in the network. To do so, we present a method based on the learning automaton in the sink node that learns about the network congestion status and assigns the proper rate to the source(patient) based on its current status(Critical or Normal). If this rate is too low network throughput decreases drastically. On the other hand, when source rate is too high it causes congestion and reduces network performance.

In the proposed protocol, variable learning automaton is used. This automaton has 3 actions as follows:

A = {source_rate_increase , no_change , source_rate_decrease}. Table 2 gives a summarized definition of the three automaton actions.

Table 2. Definition of automaton actions in the sink

Action name	Description
No_change	The network has reached stability and there is no need to change the source rate.
Source_rate_incerase	Network congestion has been reduced; therefore the source rate will be increased.
Source_rate_decrease	Due to congestion and increase in delay and packet loss, the source rate should be decreased.

Choosing the proper action is based on the following learning parameters:1) *delay*,2) *number of lost packets between two successful deliveries,3)throughput and 4)traffic class*. To calculate the packet loss rate and delay variation, the learning automaton in the sink node uses the following equations:

$$\begin{aligned} \Delta Ls(t) &= Ls(t) - Ls(t-1), \\ \Delta D(t) &= D(t) - D(t-1) \end{aligned} \tag{6}$$

where ΔLs(t) and Ls(t) denote the total loss rate variation and the value of packet loss at time *t*. Ls(t-1) is the loss rate at time *t-1*. ΔD(t) and D(t) are delay variation and delay of received packet at time *t,* respectively. D(t-1) is the value of delay in time *t-1*. In computing $Ls(t)$ and D(t) Critical and Normal packets have different weights as follows:

$$\begin{aligned} Ls(t) &= w_c Ls_c(t) + w_n Ls_n(t) \\ D(t) &= w_c D_c(t) + w_n D_n(t) \qquad w_c \geq w_n \end{aligned} \tag{7}$$

Where $Ls_c(t)$ and $Ls_n(t)$ show the packet loss rate for Critical and Normal traffics at time *t,* respectively. $D_c(t)$ and $D_n(t)$ show the value of delay for Critical and Normal packet in time *t*. After choosing an action, the automata rewards or penalizes it based on network feedback as follows:

- If $(\Delta D(t)>0 \text{ and } \Delta L(t)>0)$ OR $(\Delta D(t)<0 \text{ and } \Delta L(t)>0)$ the automaton is penalized according to equation (2)
- If $((\Delta D(t)<0 \text{ and } \Delta L(t)<0))$ OR $(\Delta D(t)>0 \text{ and } \Delta L(t)<0)$ the automaton is rewarded according to equation (3)

The larger the value of *"number of lost packets"* the higher the congestion will be. In addition, the delay of arrived packets at the sink indicates that the number of packets in the intermediate nodes' queue has been increased due to network congestion. Therefore, delay is an efficient parameter in determining network congestion.

By selecting an action, we expect to have a reduction in the number of lost packets and delay. If this does not realize, the automaton will penalize itself. Therefore, using the information obtained from the sink, the source finds out the optimal rate. This will lead to maximum throughput and congestion avoidance. The *Critical* patients get more bandwidth than others.

4 Simulation Results

To evaluate the performance of the proposed LACCP protocol, we simulated a wireless biomedical sensor network including 3 different patients. We used Opnet simulator [8]. In addition to the proposed protocol, the well known LACAS protocol was also implemented. The simulations were run using LAF protocol [9] as routing protocol and CSMA protocol as MAC layer protocol. The nodes were randomly distributed in the environment. At the beginning of the simulation, we assume all end sensor nodes (the patients) are in *Normal* condition. Patient 3 changed its status to *Critical* condition between time t=40 sec. and t=140 sec.

Table 3 shows the average end to end delay. It can be seen that the performance of LACCP protocol is better than LACAS protocol. Obviously, shorter queue lengths will cause shorter packet queuing delay. Critical packets are delay intolerant so these packets have a higher priority in entering and exiting the node, so they reach their destinations faster. Using a proper AQM mechanism which estimates the arrival rate based on queue length and channel load along with an automaton-based mechanism that determines source transmission rate will keep the queue length constant at a desirable size and avoid its sudden expansion.

Table 3 also shows the packet loss rate in the intermediate nodes. In sever congestion, the increase in channel load and queue length leads to a higher probability of loss in the intermediate nodes. So the number of accepted packets in the node is decreased. As seen in table3, the number of Critical lost packets is less than that of other classes. In LACAS only 5 rates are considered to be select by automaton which is not optimal. This indicates the adaptability of the proposed AQM mechanism in the intermediate nodes with the congestion control protocol in the sink.

Table 3. Impact of the service differentiation on average delay and packet loss

Average delay	Value	Packet loss rate	Value
Total for proposed protocol	0.41	Total for proposed protocol	0.21
For Critical Class	0.24	For Critical Class	0.07
For Normal Class	0.36	For Normal Class	0.23
Total for LACAS	3.1	Total for LACAS	0.4

Figure. 1 illustrates the remaining energy in the sensor nodes. The figure represents one of the network nodes in the bottleneck near the sink which is definitely the most energy consuming node. In the LACCP protocol, some messages are sent to the source from sink. So LACCP may use more energy than LACAS. It shows that there is no more difference between LACAS and LACCP in energy consumption.

Figure 2 shows the number of total lost packets versus the simulation time. A comparison of the loss in the LACCP and LACAS protocols will show us that the LACCP protocol has a much lower level of loss than the LACAS protocol. This is because the learning automaton-based mechanism in the sink efficiently adjusts source transmission rate and avoids congestion and loss based on the feedback received from the network. Although the LACAS protocol adjusts the source transmission rate too, as the diagram shows the LACCP protocol is more successful in choosing the optimal source rate. Furthermore, in the LACCP, at time t=50 sec. the network becomes more compatible with the situation due to the learning of the automaton. Since source transmission rate is adjusted by the automaton, the number of lost packets is reduced and as the traffic increases lost packets remain almost constant.

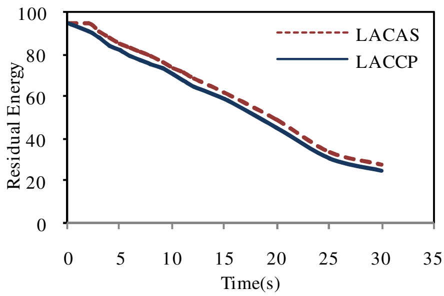

Fig. 1. Residual energy

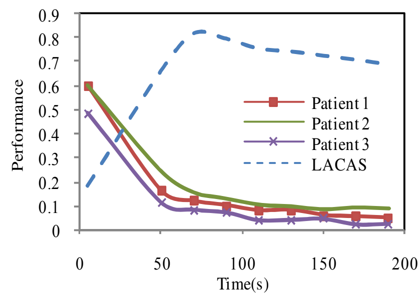

Fig. 2. Number of drop packets / number of packets generated by sensing nodes

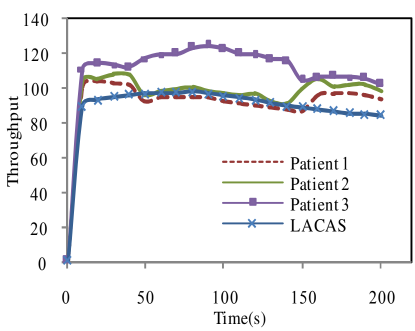

Fig. 3. Throughput versus time

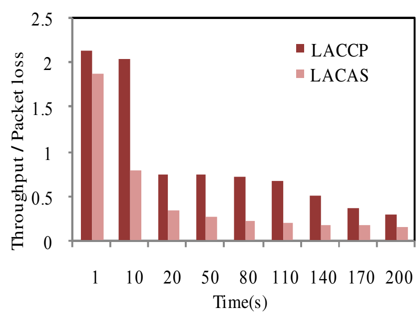

Fig. 4. *eff* parameter versus time

Figure 3 shows the throughput of both LACAS and LACCP protocols. We can observe that the proposed protocol can assign network bandwidth to each traffic class based on its priority. When patient 3 goes to Critical condition (during time interval [40s, 140s]), the system assigns more bandwidth to it. Since the LACAS protocol cannot discriminate between traffic classes, we have shown only its total throughput. Source reduces its rate due to packet loss avoidance. Reducing transmission rate should not lead to network throughput reduction. The following metric is defined in order to determine the impact of learning based congestion protocol (LACCP):

$$eff = \frac{T}{L} \tag{8}$$

Where T is total throughput and L is the average packet loss. The *eff* parameter shows the effectiveness of the protocol. The higher value of *eff,* the more favorite the answer. In figure 4 *eff* parameter is plotted versus time. LACCP protocol has higher throughput and lower packet loss than LACAS. So LACCP is more effective than LACAS.

5 Conclusion

In this paper we presented a congestion control protocol based on learning automaton for healthcare applications in WBSNs. The proposed congestion control protocol namely, LACCP can adjust intermediate node arrival rate and source rate using learning automata. Two different traffic classes namely *Critical* and *Normal* were considered. In order to control congestion, a mechanism based on the learning automaton has been placed in the sink. Using weighted scheduling mechanisms, higher priority classes are given better quality of service and more bandwidth than the lower priority classes. The simulation results indicate that the proposed protocol, by adjusting source rate, avoids loss caused by congestion. Furthermore, it has been shown that the LACCP achieve higher performance and lower packet loss than LACAS.

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CodaQ: A Context-Aware and Adaptive QoS-Aware Middleware for Activity Monitoring

Shahram Nourizadeh, Ye-Qiong Song, and Jean-Pear Thomesse

INPL - Nancy University, Loria, France
{Shahram.Nourizadeh,Song,Thomesse}@Loria.fr

Abstract. For providing real-time data collecting in a telehealthcare system composed of wireless sensor network and home automation network, a middleware called CodaQ is designed. It provides context data and takes into account QoS requirements of the applications. In this paper, we show how the data are modeled for including context information and how the QoS requirements are handled within a middleware. First measurements on a test bed have been carried out showing the good performance of our design.

Keywords: Context-aware Middleware, adaptive QoS, Telehealthcare, Wireless Sensor Networks.

1 Introduction

Activity monitoring (or actimetry) of the older people at home is one of the important applications of the telehealthcare systems. Actimetry needs to collect in real-time sensor data through an efficient communication system with QoS guarantee. Wireless sensor network (WSN) is an emerging technology for building telehealthcare systems and has incited important research efforts [1]. One of the main research topics is to provide the QoS for the sensor data transfer in terms of timeliness and reliability under stringent energy constraints. However how to map the application requirement and the network QoS services needs still further investigation.

In a typical activity monitoring system data traffic flows can be classified into 3 categories with different priorities: 1. Medical sensors; 2. Environmental sensors; 3. Multimedia. Medical data flow has the highest priority and multimedia the lowest one. Data collection can be achieved through a home gateway. Different data collection strategies can be applied in each category: Event-based, periodic or mixed data collection, which demand managing the QoS requirements (by applying priorities) and temporal coherence (time stamp). The QoS requirements of the sensor data are determined by sensor data type and the condition of the patient. For example, the medical information like ECG may require a higher priority than the other sensors when a patient has an unusual heart rate, in this case the home gateway must be able to give the higher priority to ECG data flow. The temporal coherence is needed for multi-sensor data fusion (e.g. related data are collected during a coherent time window) and this can be achieved by time stamping at the home gateway.

Moreover sensor data should be interpreted within their current context. This can be achieved by using context-aware computing. Context is any information about the

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user and the environment that can be used to enhance the user's experiences [2]. Context-aware systems represent extremely complex and heterogeneous distributed systems, composed of sensors, actuators, application components, and a variety of context processing components that manage the flow of context information between the sensors/actuators and applications [3]. The objective of our work is to deduce the state of the patient at any moment and the contextual information helps us to do this.

2 Related Works

In the literature, several context-aware middleware have been proposed. ConStruct [4] is a knowledge-based pervasive computing middleware that provides semantically unification over a range of home- and web-based automation systems. It is a sensor-fusion-based middleware for smart homes. In ConStruct all data are modeled using the Resource Description Framework (RDF) [5], which provides a standardized way to model contextual information and properties.

Another adaptive middleware design for context-aware applications is presented in [6]. The middleware abstracts the applications from the sensors that provide context. It also aims to implement autonomic properties, such as self-configuration and failure tolerant. The goal in the design of this middleware has been to provide adaptation with good performance. The approach assumes that Context Providers (CPs) are able to estimate their QoC (Quality of Context: precision of the information provided by middleware about the context).

[7] presents the design and implementation of a middleware approach for context-awareness, and adopted fuzzy logic as an intelligent reasoning method for selecting data dissemination protocols in the design of the decision mechanism. The approach uses a context space theory model shown in [8] for modeling the fundamental nature of context and enable context and situation awareness for context processing. Its context model gives a common representation for context that all entities in the environment use of pervasive computing. Instead, it provides a common base on which various reasoning mechanisms can be specified to handle context.

[9] presents MidCASE a middleware to support the context-aware application development for wireless sensor networks. The middleware has five layers and two cross layers: hardware abstract, service registry, context model, reasoning and application presentation layers; energy management module and security module.

Numerous other attempts to build middleware or infrastructure for context-aware systems have been made also, but they have provided only partial solutions; for instance, most have not adequately addressed issues such as QoS, mobility, fault tolerance or privacy. To fully use the benefits of context-aware system, an infrastructure which enables QoS self-adaptation and protocol interoperability among heterogeneous components is required. In these systems, any change in context provision must be detected quickly and adaptation occurs swiftly. This is important in telehealthcare systems that monitor a person with health problems. A number of existing approaches appear to be quite suitable and efficient but none of them appears to be a perfect match for the requirements.

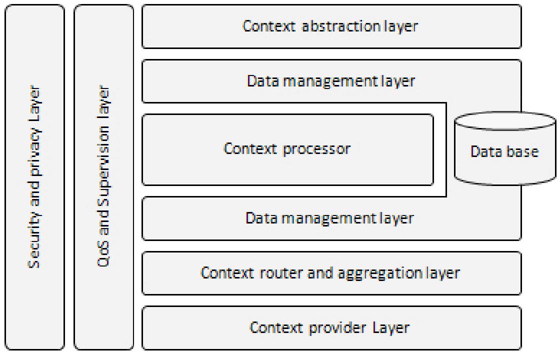

Fig. 1. Reference model

Table 1. Comparison of surveyed Middlewares

	Service or Layer							
Middleware	Context abstraction	Supervision and QoS	Database	Context processor	Data management	Context router and aggregation	Context provider	Security / privacy
ConStruct	yes	no	no	yes	no	yes	yes	no
[6]	yes	yes	no	yes	no	yes	yes	no
[7]	no	no	no	yes	no	yes	yes	no
MidCase	yes	no	no	yes	no	yes	yes	yes

In order to consider the challenges we discussed before, we defined a reference model (Fig. 1). This model presents all modules that a Middleware must have, to be able to deal with the challenges and ensure a real context deduction. In this model:

- Context abstraction layer provides an abstraction of the context for context-aware applications.
- QoS and Supervision layer guarantees the supervision of the system and applies runtime QoS need.
- Database saves the events and states detected from the context.
- Context processor layer uses the raw data provided by the context router, to reason the context.
- Data management layer controls the databases and ensures the management of all data that are exchanged between the other layers.
- Context router and aggregation layer is a gateway between the context provider layer (sensors) and the middleware.
- Context provider layer is a distributed application installed on the sensors to detect and send the events to the middleware.
- Security layer is the responsible for providing the security of the system.

Table 1 summarizes the capabilities of the surveyed solutions based on considered reference model and shows that comprehensive solutions do not yet exist. In this paper we present CodaQ, a context- and QoS-aware health and activity monitoring middleware, which is the key building block of a global telehealthcare system. CodaQ introduces fuzzy decision support and addresses a large subset of the requirements listed in Table 1 except security and privacy which are our future work.

3 Data Modeling for Taking into Account the Context

In CodaQ all data are given a uniform representation, and their level of abstraction is raised through the use of data format definitions for *raw event*, *deduced state, virtual sensor, zone, query and query reply* that will be detailed in the following.

The **Raw Event** is the output of a sensor on which no process was accomplished; it is the input of the application. The Raw Event shows an event detected by a sensor on a specific place, like movement or presence of a person, window or door opened or closed, light switched on or off. The Raw Event is presented by **RawEvent** parameter:

RawEvent (Id, Time, SensorID, {Values}, Zone).

For example **RawEvent**(10,22/11/2010-14:15:23,316,21,Room01), means that the raw event number 10 is detected by sensor number 316, at 14h15m23s of 22/11/2010, at Room01 and the measured value is 21.

The **Virtual Sensor** is the main component of hardware abstraction in our middleware. Virtual sensors abstract from implementation details of access to the sensor network and correspond either to data streams received directly from sensors or derived from other virtual sensors accessible through the network (thus a set of virtual sensors). The virtual sensor descriptor in our architecture is presented as:

VirtualSensor(Id, {Sensors}).

Our middleware creates these virtual sensors dynamically based on context state (state-based virtual sensor formation).

The input of a **VirtualSensor** is **RawEvent** and its output is a deduced state which presents the state of the context. The deduced state is the result of the processes in context processor on the raw events, and presents the context's actual situation. The deduced state is represented by **DeducedState** descriptor:

DeducedState (Id, Value, Category, Time, Zone/Place, VirtualSensorId).

For a user, the value of **DedusedState** could be: Fall, Leave/Arrive, Sleep, Eating, Reading etc. For example **DeducedState** (128,"Eating", "Normal", 22/11/2010-16:10:12, "Kitchen", 257), means the people was eating at 22/11/2010-16:10:12 in the kitchen, this state is a normal state and in deduced by virtual sensor which has Id 257.

Zone, presents the location of a given event or state:

Zone (Id, {Sensors}).

Query is the command generated by the system to an actuator or a sensor. Light switch off, change the lighting level, open the door are some examples of a query. It could also be used for the supervision of the system in order to detect any failure in the hardware or the communication links. The query is represented by Query descriptor:

Query (Id, Category, {Sensors}, {Actuators}, Zone, Supervision (Bool)).

If supervision is true, then the answer will be a **QueryReply** which is presented by **QueryReply** descriptor as the acknowledgement of the sensors or actuators to a Query:

QueryReply (Id, QueryId, {Sensor}/{Actuator}),

and if supervision is false, the answer will be a **RawEvent**.

4 Architecture of CodaQ

In our architecture (Fig. 2) it is **Context Collector** (equivalent of Context router and aggregator in reference model) that collects the context raw events from the distributed context providers and saves them in the Raw Event data base. This layer has a Queue Manager sub-layer which controls the input buffer by information received from QoS Specification Provided.

The next layer is the data management layer, which has 2 sub layers:

- **Data Manager:** receives queries from different components of the middleware, executes them and resend the results.
- **Database:** consists of six databases.

Context process layer deduces real context state from raw events (basic sensed context data) using fuzzy rule-based reasoning techniques, and also checks for knowledge consistency in the fuzzy context knowledge base. In addition, temporal and spatial

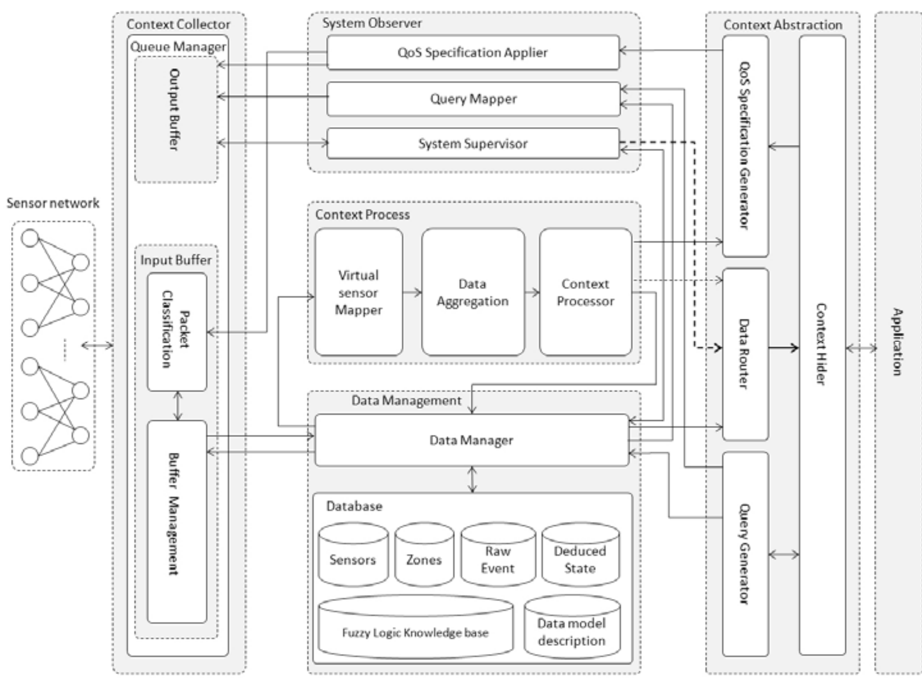

Fig. 2. CodaQ's architecture

validation must be taken into account. Temporal validity is defined as the period of time to which a single instance of context information is applicable, and spatial resolution is defined as the precision with which the physical area, to which an instance of context information is applicable, is expressed [10]. To consider these needs, this layer has three sub layers:

- **Data Aggregator:** aggregates the context information by using Raw Event Database and Virtual Sensor information and provides them to Context Processor Layer. This layer verifies the temporal validity in a given time window. If one or more data are not in the time window, the layer request from Query generator layer to send a query to the sensors in order to provide fresh data.
- **Virtual Sensor Mapper:** provide necessary information about all virtual sensors of the network. It uses Sensor and Zone Databases to create virtual sensors and provides them to the Data Aggregation layer. The concept of Virtual sensor is used to apply the spatial validity.
- **Context Processor:** uses information provided by Data Aggregation layer, processes them in order to deduce real state of the context and saves deduced states in the Deduced State Database.

QoS observer layer is the next layer of the middleware which has three sub layers:

- **QoS Specification Applier**: In our design QoS observer applies QoS in two levels: Embedded and Run-time State-based QoS. For the embedded QoS guaranty, we use the adaptive routing algorithm which optimizes the resource utilization by considering Energy, Mobility, Failure history and Load of the nodes [11]. The Run-time State-based QoS is based on priorities, defined by application in a given time in order to adapt the resource needs of the application. QoS Specification Applier uses run-time information about the context to choose the most suitable configuration of applications and middleware services. This requires that the middleware has a specification of elements in the context, and QoS specifications. Some examples of context information that can be used to improve the QoS are: user's location and user's health state. The Context Collector can then prioritize and schedule the information delivery based on which information elements are most important to the user, and can select information processing based on user characteristics and resources, and allocate the buffer to the most important operations.
- **System Supervisor:** it creates Queries and sends them to the specified destinations (Sensors and Actuators) in order to monitor health state of the installed sensors and actuators and detect any failure in them or the communication links.
- **Query Mapper:** uses Sensors and Zones database and generates the necessary queries in order to provide the latest (fresh) information of the sensors.

Finally, the **Context abstraction** layer uniforms the information and data transferring between Application and the Low level layers (Middleware and Context providers) by applying data model definitions. It has three sub layers:

- **Context Hider:** receives the requests from application and sends it to QoS Specification Generator and Query Generator layers. It also receives results of the queries and sends them to application layer.
- **Query generator:** generates persistent controls on demand of application layer. This layer is the bridge of communication of application layer with the sensors

and actuators and allows applications to extract desired context information from the networks.

- **QoS Specification Generator:** generates QoS Specifier by using QoS need of the application, received from Context Router layer.

5 Implementation and Performance Evaluation

A prototype has been implemented to verify the feasibility of our proposals, based on our laboratory apartment in Colmar. The programming environment of the middleware is Visual Studio .Net 2005 C# and ASP .Net and the service discovery is based on SOAP. The prototype utilizes a SQL server database. The prototype utilizes Imote2 sensors in the sensor network side. The programming environment for these sensors is Imote2.Biulder SDK under Visual Studio .Net 2005 C# and Microsoft .Net Micro Framework 2.5, based on TinyOS 2.0.

We examined the response time of a context query, which is defined as the interval between the time when the query is issued from an application by receiving the data from the sensor and the time when the application receives the query result as a feedback from the actuator. In this scenario, we use Imote2 motes to sense outdoor luminosity. The sensed data will be sent to the gateway and will be processed by the middleware, and based on the result, the indoor luminosity will be varied.

Table 2 shows the time breakdown of a query in our system. The results presented in this table are the average of 10 measurements. Data collection is the time spent on getting the context attribute values from the network of Imotes, Context processing is the time the the context processing takes to evaluate the data and generate the query, Query generation is the time the system spends on creating the query and finally Reply is the time required to send the query result to the application.

In the table we see that, the total response time of a query in our system is less than one second. The collection of context data from the sensor network takes 34% of the total time and the most time-consuming task among the others is the reply time which takes 48% of total time. The time for context processing takes 14% and the query generation time is just 4% of the total response time. If we use direct command to an actuator we do not have the context collection and processing times. That means by automation the home environment by our system, we add an overhead of 273 ms for context collection and 14% for context processing or 48% of the total response time which seems to be acceptable as a cost of automation of the context processing and control.

Table 2. Response time

Task	Time (*ms*)	% in total time
Context collection	378	34%
Context processing	112	14%
Query generation	34	4%
Reply	237	48%
Total time	**797**	

6 Conclusion and Future Work

The experience gained through our work showed us the lack of a bridge between the healthcare applications and the sensor networks in a telehomecare system, to guarantee QoS needs, for supervision of the system and for easy configuration and installation of the sensor and actuators.

For these reasons, we developed CodaQ, a context-aware and priority-based adaptive QoS middleware. In this middleware all data are given a uniform representation, and their level of abstraction is raised through the use of basic data modeling. A context-based adaptive QoS method was implemented on the system, in two levels: Embedded and State-based QoS.

As our future work, we plan to investigate the extended use of our data modeling system to consider a wider class of context data. Moreover, since in many situations available context data may be insufficient to unambiguously determine the activity performed by a user, we are investigating the use of fuzzy ontologies to deal with uncertainty and fuzziness.

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Physical Activity Monitoring with Mobile Phones

Lin Sun[1], Daqing Zhang[1], and Nan Li[2]

[1] Handicom Lab, TELECOM SudParis,
9, Rue Charles Fourier, 91011, France
{LinSun,DaqingZhang}@it-sudparis.eu
[2] National Key Laboratory for Novel Software Technology
Nanjing University, Nanjing 210093, China
lin@lamda.nju.edu.cn

Abstract. The rich sensing ability of smart mobile phones brings an unique opportunity to detect and long-term monitor people's physical activities. However, with mobile phone the application has to comply with people's usage habit of it and thus capture the right moment to recognize activities, which will potentially cause great in-class variances. As a result, the model potentially becomes complex and costs much computing resources in mobile phone. This paper recognize people's physical activities when they place the mobile phone in the pockets near the pelvic region. Experiment results show that the accuracy could reach 97.7%. To reduce the model size, evaluation of each feature attribution contribution for the accuracy is performed. And the result shows that we can cut the feature dimension from 22 to 8 while obtaining the smallest model.

Keywords: activity recognition, machine learning, mobile phone, accelerometer, feature reduction.

1 Introduction

Long-term physical activity monitoring of mass population provides rich opportunities for monitoring people's physical active patterns and finding opportunities to changing unhealthy lifestyles. For example, to change the sedentary lifestyles, Sharkra [1], Fish'N'Step [12] and UbiFit Garden [6] use interesting games which adopts people's physical activity (i.e. walking steps) as the input to stimulate them to be physically active. However, currently such systems require additional sensing devices to be attached on human body, which is troublesome and costly for deploying to large population. Mobile phone based physical activity recognition, which embracing the rich sensing power in existing phone platforms, requires no additional devices and no extra spending. And thus it becomes the ideal solution for physical activity monitoring. With this technology, we can easily monitor when and where individuals perform what kind of physical activities, making them more aware of their heath and lifestyle status. Besides, more sophisticated applications can devised to help change the prevailing sedentary lifestyle. For example, not only can we stimulate people to conduct more

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physical activities by games only running within the mobile phone platform, but also we can also find valuable opportunities from their daily activity patterns, such as encouraging bicycling for short-time driving, or driving to a little further place from the destination and then walking there.

Despite the increasing sensing power of mobile phones, mobile phone based activity recognition still has many difficulties that so far greatly prevent it from mass adoption. We identify three key issues that are critical to mass adoption of such application and are different concerns from previous sensor based activity recognition studies.

I. Complying with people's usage habits. Since people use mobile phones primarily for communications and people have various usage habits, such as placing them in different positions and orientations unintentionally while carrying them, the system has to comply with their usage habits instead of asking them to place their mobile phones in predefined locations and orientations.

II. Finding the right activity recognition opportunity. The fundamental setup of activity recognition is that the sensors can capture discriminative signals of the target activities. However, In the case of mobile phone based activity recognition, not all the deployment of them can be used for activity recognition, such as when people put the mobile on the desk instead of carrying them on, or just sway with their arms when they sit down. Consequently, we have to find the right moment that the mobile phone is able to detect the right body movement signals.

III. The activity recognition application has to be resource saving. Power consumption is a critical concern for mobile phone applications. As the activity recognition program is supposed to be running all along in the background of the mobile phone system, it easily causes battery drain. Besides, large amount of computations also slows the mobile phone and affects the running of other applications, which is not acceptable for user acceptance. And thus the activity recognition application should be small enough to save resources.

However, as the mobile phone may be placed in different body locations with diverse orientations, the signals may reflect movements of different body parts and different sensor orientations. As a result, it leads to the great in-class variance and produces big classification models, which is in conflict with resource saving.

Capturing the opportunities when people put their mobile phones in the pockets around the pelvic region, we recognize 7 typical physical activities that people conduct daily in this paper, including stationary, walking, running, bicycling, ascending stairs, descending stairs, and driving. Our contributions in this paper lie in the following three parts. Firstly, we conduct experiment to examine the opportunities of recognizing physical activities using the accelerometer sensor embedded in the mobile phones in the scenario. Secondly, based on the extracted 22 features, we evaluate the classification abilities of 6 common used machine learning algorithms. The result reveals that Support Vector Machine [4] achieves the best performance at 97.7%. Thirdly, through the proposed feature reduction method, we successfully reduce the feature dimension from 22 to 8, while obtaining the smallest model size.

2 Related Work

In this section we introduce the activity recognition studies that collect sensing data from mobile phones or from sensor platforms that share similar usage pattern. The major concern is that mobile phone has various possible deployment positions and orientations. An earlier work conducted by Lester et al. [11] investigated three representative locations, including the wrist, the waist and the shoulder and found that the general HMM model for all the three locations performs only a slightly worse than that of the separate HMM model for each location. However, the sensor boards in the study are constrained by traps or bags, which limit the orientation freedom of themselves, and also these locations aren't the usual positions for mobile phones. To solve the varying orientation problem when carrying on mobile phone freely, Yang [17] computed the vertical and horizontal components of the sensor reading based on gravity estimation work of Mizell [14]. However, results in [13] showed that the method failed to outperform the method which just adds the accelerometer magnitude as one dimension of the sensor reading. It is probably caused by the inaccuracy of magnitude estimation method. And also it didn't consider the varying deployment positions of mobile phones.

A few studies, like ours, focused on activity recognition with data collected from commercial mobile phones. Kwapisz et al. [10] collected data from mobile phones carried in the front pants leg pockets and recognize similar activities like us with machine learning techniques. However, the mobile phones in in fixed orientations and the pocket locations is specific, which limits the usage in real life. Gerald et al. [2] introduced several aspects of activity recognition with mobile phones, including the wearing positions, sampling rate, activity types and mobile phone requirement. However, it didn't introduce the recognition solutions.

Different from above works, we study the possibility of activity recognition with mobile phones freely placed in the pockets near pelvic region, which is practical for daily usage of such system. Based on the extracted features, we evaluate the performances of different recognition algorithms and the impact of the sampling window length. And feature reduction is performed to get the smallest model size while obtaining high recognition accuracy.

3 Assumption, Experiment and Feature Extraction

3.1 Assumption

As demonstrated in [15], the pelvic region is an ideal deployment position for recognizing various physical activities. And also the pockets of normal clothes are designed around this region (i.e. the front and rear pockets of jeans, the front pockets of the coat as shown in Fig 1(a)). As revealed by [8], over 60% men get used to putting their mobile phones into their pockets. And thus we are trying to seize the opportunity when people place their mobile phone inside their pocket around the pelvic region to recognize their physical activities.

We choose all the pockets shown in Fig 1(a) as the potential mobile phone deployment positions. Due to the constraints of pocket shapes, we observed

(a) (b)

Fig. 1. (a) Pocket locations. For each pocket shown, there is a corresponding one in the left side of the body. (b) Four phone orientations when users put the mobile phone into the right front jean's pocekt

Table 1. The sampling time of the each activity during the experimentation

Activity	Station	Walk	Run	Bicycle	Ascend stairs	Descend stairs	Drive	Total
Time(Hour)	10.4	9.8	6.3	6.6	4.6	4.0	6.5	48.2

that people usually put the mobile phone into each pocket with four typical orientations. For example, Fig 1(b) shows the scenario when people put the mobile phone inside the jeans pocket.

In this paper we choose seven typical physical activities that people conduct daily, including stationary, walking, running, bicycling, ascending stairs, descending stairs and driving. Stationary is the status when people are still, including standing, sitting and lying down. For the activities people conduct while sitting down, the mobile phone isn't suitable to be placed in the rear pocket of the trousers, since it may be crushed by human body.

3.2 Experiment

We conduct experiment to collect the accelerometer data with Nokia N97 at a sampling rate of 40Hz for each activity with each possible combinations of location and orientation. Seven subjects from our campus participated in the experiment. After launching the sampling application, the participants put the mobile phone into the target pocket and conduct the activity for a duration about 5 to 10 minutes. And then they take the mobile phone out and terminate the application, which saves the accelerometer records during this period of time into a file. While residing in the pockets, the mobile phone is completely free to rotate or move. Since the first and the last few seconds of the records are the overhead when people put the mobile into the pocket and take it out of the pocket, they are removed from the official record. Totally we get 48.2 hours training data as shown in Table 1.

3.3 Feature Extraction

As demonstrated in [13], the accelerometer magnitude does help improve the classification accuracy as one dimension of sensor readings. So we add it to the sensor reading and prepare a 4-D raw data set Then we use half overlapping window to separate the data record into a number of equal-sized windows. We evaluate the influences of different window length for the following reasons. Firstly, it's intuitive that long time observation should help to recognize the activities to some extent. So we want obtain the optimized window length to get the best recognition accuracy. Secondly, within the range of acceptance, larger window length implies that the activity recognition frequency is smaller, which could save the energy consumption.

We employ five feature types including Mean, Variance, Correlation, FFT Energy and Frequency-domain Entropy because they have produced good results in previous works [16,13]. In total, 22 features are extracted from each window (4 features for each Mean, Variance, Energy, Frequency-Domain Entropy, respectively, and 6 features for Correlation) and forms a 22-D feature vector. All the feature vectors forms a feature matrix with each column corresponding to one element of a specific feature type. The data of each column is normalized to [0,1].

4 Result Analysis

In this section we firstly compares the recognition accuracies of different machine learning algorithms and the impact of the window length on the performance. After that, we perform feature reduction to get a small and compact model.

4.1 Recognition Accuracy Comparison

WEKA toolkit [7] and LibSVM [5] are used to perform the classification with the extracted features. We adopt *10-folder cross validation* to get the final accuracy. All the features are randomly divided into 10 equal-sized folders. Each time we select one folder as the testing dataset and the rest as the training data set. Then the final accuracies is generated by averaging the cross validation results. We also perform grid research to get the best parameters for each classifiers. The classification accuracy of each algorithms with respect to different window length is revealed in Fig. 2. It can be seen that SVM performs the best (97.7%) comparing with the rest algorithms. And following is Random Forest [3] (96.5%), whose performance is almost the same when the tree number exceeds 20. Naive Bayes [9] and RBF Network performs the worst around 70%. When the window length grows from 1 second, the classification accuracy increases for each algorithm. For SVM and Random Forest, it reaches a stable level when the window length is over 6 second. It validates our intuition that with longer time observation, the classification accuracy increases and then reaches a stable level. To save the resource consumption, reducing the classification frequency would be acceptable with stable accuracies for some applications. However, the drawback is that the classification granularity would become coarse when the window length increases.

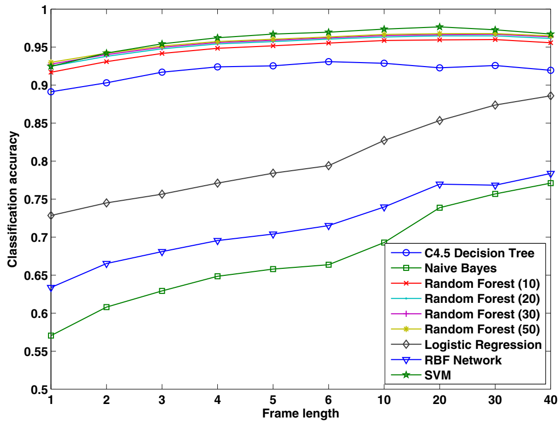
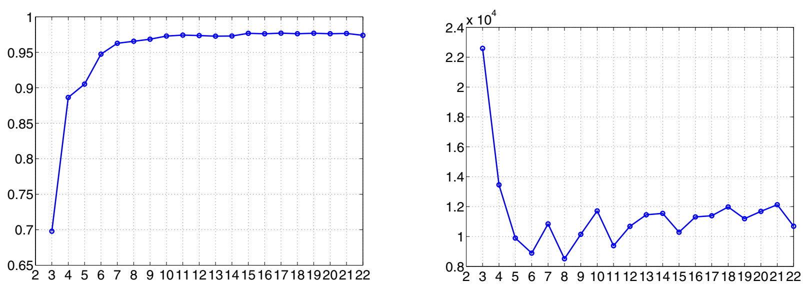


Fig. 2. The classification accuracy of different algorithms with respect to different window lengths



(a) (b)

Fig. 3. (a), Feature Validation Result. The least contribution feature is extracted in each loop and the horizontal dimension is the number of left contributes. (b), The number of Support Vectors with different dimensions.

4.2 Feature Dimension Classification Contributions and Reduction

To obtain a compact classification model, we evaluate the feature attribute contribution according to Algorithm 1. We choose the window length as 6 seconds and evaluate the feature contributions with SVM. We show the recognition accuracy with the number of left feature dimensions in Fig. 3 (a). It can be seen that when the feature number exceeds 7, the recognition accuracy become stable. As the computation cost when predicting with SVM model is directly related with the number of support vectors and also the feature dimensions, here we compares the support vector numbers with different attribute numbers of the model in Fig. 3 (b). It's surprising to see that the number of support vectors decreases to the smallest level when there are 8 attributes and then increases with more feature attributes. As a result, choosing these 8 attributes can reduce the number of support vectors and feature dimensions.

Algorithm 1. Feature Contribution Evaluation

```
DS is the feature dataset T is the feature dimension of DS
while 1 < T do
    Acc_max ← 0
    for t = 1 to T do
        D_t ← DS
        Exclude the t^th dimension from D_t
        Perform 10-folder cross validation on D_t and get the average accuracy Acc_t
        if Acc_max < Acc_t then
            Acc_max ← Acc_t
            MinLossD ← t
        end if
    end for
    Exclude the MinLossD^th dimension from DS
    T is the feature dimension of DS
end while
```

5 Conclusion

Mobile phone based activity recognition, which caters to the demand of long-term physical activity monitoring, has to comply with people's usage habits, capture the right moment for activity recognition and save resource. This paper explore the opportunity of recognizing seven typical daily physical activities when people put their mobile phones inside the pocket near the pelvic region. Experiment shows that the recognition accuracy reaches 97.7% when people put their mobile phones freely into the pockets. To obtain a compact model, feature validation is performed to evaluate the contributions of each feature attribute and feature reduction is conduct the get rid of the little contribution attributes. Result shows that we can reduce the feature dimension to 8 and meanwhile obtain the smallest model with little loss of recognition accuracy.

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Guidelines for Increasing Prompt Efficiency in Smart Homes According to the Resident's Profile and Task Characteristics

Mike Van Tassel, Julie Bouchard, Bruno Bouchard, and Abdenour Bouzouane

LIARA Laboratory, Universite du Quebec a Chicoutimi (UQAC)
555 boul. Universite, Saguenay (QC), Canada, G7H 2B1
{Mike.Van-Tassel,Julie1.Bouchard,Bruno.Bouchard,
Abdenour.Bouzouane}@uqac.ca

Abstract. Smart homes provide a technologically enhanced environment that helps user's complete activities of daily living, thus increasing their autonomy. However, predominant use of verbal prompts in smart homes, with little knowledge of their effectiveness, affects significantly their efficiency by providing prompts that are not optimized with the profiles of the users and the characteristics of the tasks. In order for prompts to be effective, they have to compensate the deficits of its users by exploiting their remaining strengths. To contribute solving the issue, we present, in this paper, basic guidelines that are useful for increasing prompt efficiency in smart homes. We identify relevant significant individual profiles and task characteristics that affect prompt efficiency and how to use prompts accordingly. In addition, we illustrate our efforts to validate the proposed guidelines by giving preliminary results from our ongoing experimentations and by presenting the experimental protocol and software application being used.

Keywords: Smart Homes, Prompts, Efficiency, Guidelines, Individual Profiles, Individual variables, Task Characteristics, Task Variables.

1 Introduction

A smart home can be defined as a technologically enhanced environment that helps its resident in the achievement of his activities of daily living, thus increasing their autonomy [1,2]. However, predominant use of verbal prompts in smart homes [3], with little knowledge of their effectiveness, affects significantly the efficiency of these technological tools by providing prompts that are not optimized with the profiles of their users and the characteristics of the tasks. For example, while verbal prompts are effective for normal functioning individuals, they are highly ineffective for individuals with severe deficits in verbal comprehension [4,5]. In order to maximize its potential, it is essential for smart homes to compensate the deficits of its users by using prompts that exploit their remaining strengths [1,3,6,7,8]. Moreover, the prompts in these homes, while simultaneously accommodating the profiles of its users, also have to be compatible with the characteristics of the tasks currently in progress [3]. Such accommodation and compatibility can only be achieved by having

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a greater knowledge of individual profiles and task characteristics related to prompt efficiency and by increasing the variety of prompts used [6]. However, due to the prevalence of research in the smart home paradigm being mainly directed towards sensory devices and behaviour recognition, such information is relatively scarce [1,2,9]. Consequently, the literature on which prompt to use is limited and, as a result, the proportion of individuals that fully profit from the great potential of smart home technologies is reduced [6].

In an effort to contribute solving this important issue, we propose, in this paper, basic guidelines that are useful for increasing prompt efficiency in smart homes. Our contribution takes several forms. Firstly, we describe thoroughly and synthetically prompts that can be used in smart homes (see table 1). Secondly, we present major individual profiles and task characteristics that significantly impact prompt efficiency (see table 2). Thirdly, and most importantly, by synthesizing and vulgarizing crucial data on prompt efficiency found in the literature of numerous paradigms (e.g., psychology, education, medicine), we offer essential guidelines that indicate which forms of prompts to use according to significant individual profiles and task characteristics (see table 3). Finally, we illustrate our efforts to validate the proposed guidelines by giving preliminary results from our ongoing experimentations and by presenting the experimental protocol and software application being used.

2 Overview of Prompts Compatible with Smart Homes

Prompts can be considered as hints, suggestions and reminders that increase the probability of a desired behavioural outcome [10]. As shown in table 1, we can identify 4 main categories of prompts that can be used in smart homes: auditory, pictorial, video and light. By far the most used in smart homes, **auditory prompts** offer a number of options that increase autonomous behaviour [1]. These prompts, which require devices such as speakers and headphones, can be used as a verbal, sound or musical form. Verbal prompts, which consist mostly of verbal step by step instructions, are an easy and interesting option for increasing task completions in smart homes [4]. Both sound prompts, which consist of different kinds of sounds, and musical prompts, which consist of different types of music, provide content free information that increase autonomous behaviour in a non-intrusive way. **Pictorial prompts** are a relatively cheap option for providing visual instructions. They can be used in a photographic or textual form. The photographic form can be described as a combination of colors, shapes, images and pictures often used to visually demonstrate a sequence of step by step instructions. The textual form, by using the alphabet in a number of ways, describes, amongst other possibilities, step by step descriptions in a visual and textual manner. **Video prompts**, by requiring electronic devices such as computers, gives the possibility to combine the advantages of auditory and pictorial prompts (i.e., a picture of an object with a verbal instruction) [4]. Video prompts can also be used in a modeling form, which provides, with the help of a model performing a task, dynamic visual and auditory step by step instructions [10]. **Light prompts**, which require a light bulb or a laser pen, offer a number of minor but essential benefits (e.g., increasing attention by directing where to focus one's energy) not seen with other prompts [1]. These advantages are made possible by varying the intensity or color of the lighting and by using the light for pointing objects or for flashing.

Table 1. Portrait of prompts compatible with smart homes

Type of prompts	Devices necessary for prompt use	Different forms of prompts	Description of forms
Auditory	Speakers Portable audio devices Headphones Handheld systems	Verbal	Step by step instructions Feedback Questions
		Sound	Alerts, reminders
		Musical	Music
Pictorial	Projectors Screens Computers Handheld systems	Photographic	Colors Shapes Images or pictures
		Textual	Key words Sentences Textual descriptions
Video	Projectors Screens Computers Handheld systems	Pictorial	Same as pictorial, but with auditory
		Modeling	Video of a model performing a task
Light	Light bulbs Laser pens	Light	Intensity Colors Flashing Pointing

All these prompts can be used to help a resident carrying out tasks and activities of daily living. A task can be defined, in the smart home paradigm, as a sequence of steps organized within a time-frame [1]. Given that a task is composed of several steps, each requiring instructions that fit their own characteristics, it is essential to use a combination of prompts that accommodate the particular characteristics of each steps. This strategy is particularly important with tasks that are composed of steps that differ in nature. For example, certain steps are of a cognitive nature (e.g., counting eggs) and others of a manual nature (e.g., stirring hot sauce). Steps that are verbal in nature require visual instructions that do not interfere with the step currently being done. The same phenomenon is observed with steps of a visual nature as they require instructions of a verbal nature in order to minimize interference [9]. Furthermore, a sequence of prompts closely or simultaneously used in a task also has to differ in their nature in order to minimize interference. For example, the near or simultaneous use of verbal prompts giving instructions for cooking pasta can confuse the individual and consequently make him forget or mix up the information.

3 Which Variables to Consider before Choosing a Prompt?

There are two main factors that significantly affect the efficiency of prompts and, as a result, are crucial to consider: individual profiles and task characteristics [5]. The effect of these factors on the efficiency of prompts is cumulative [3]; therefore, it is essential when choosing a prompt to at least take into consideration individual and task variable described in table 2. Other individual variables (e.g., preferences, age, intelligence, etc.) and task variables (e.g., number of steps, length) also have an incidence on prompt efficiency. However, given the scope of the paper, they will not be discussed here in order to focus on the most relevant variables to consider.

Table 2. Significant individual and task variables that affect prompt efficiency

Factors that affect prompt efficiency	Sub-categories of factors (individua and task variables))	Description of sub-categories
Individual profiles	Diagnostics (general cognitive deficits associated with pathology)	Alzheimer's disease Traumatic head injury Intellectual disability
	Personal abilities	Verbal or visual ability
	Specific cognitive deficits (specific difficulties with tasks associated with a particular individual)	Lack of initiative Forgetfulness of steps Inaccurate task completion Lack of attention
Task characteristics	Task familiarity	Familiar or unfamiliar
	Task complexity	Easy or complex
	Nature of task	Manual or cognitive

As seen in table 2, there are three **individual variables** that have a significant impact on the efficiency of prompts: diagnostics (i.e., Alzheimer's disease, traumatic head injuries and intellectual disabilities), personal abilities (i.e., verbal and visual) and specific cognitive deficits (i.e., lack of initiative, forgetfulness of steps, inaccurate task completions and lack of attention). As regards to **diagnostics**, Alzheimer's disease is the most common form of dementia and the leading cause of cognitive impairment [6]. Individuals diagnosed with this disease progressively suffer from memory loss, aphasia, agnosia, apraxia and executive dysfunctions [8]. These deficits affect the efficiency of every prompt, but we can reasonably assume that the presence of memory loss, aphasia and executive dysfunctions particularly impacts auditory prompts. Traumatic head injuries are an acquired injury to the brain that can result in a number of deficits (e.g., memory, attention, abstract thinking, etc.), which, depending on the severity and type of deficits, generally affects equally the efficiency of each prompts [6]. Intellectual disabilities are a developmental disability defined by significant shortcomings in adaptive behaviour and intellectual functioning [6]. Deficits associated with this disorder affect the efficiency of every prompt, but its influence, due to the high prevalence of language deficiencies, is particularly felt with auditory prompts [5]. Regarding **personal abilities**, individuals who possess strong visual abilities have an aptitude to visually represent, amongst other possibilities, the sequence of steps in a task. Conversely, individuals with strong verbal abilities have an aptitude to symbolically represent the sequence of steps in a task. Due to their iconic nature, visual prompts are the most effective prompts when used with individuals possessing strong visual abilities. In contrast, auditory prompts, given their symbolic nature, are the most effective prompt when used with individuals who possess strong verbal abilities [4,5]. As for **specific cognitive deficits**, individuals who lack initiative, forgets steps or inaccurately complete tasks, performs efficiently with the guidance of video prompts, and to a lesser extent, auditory and pictorial prompts [10]. Regarding those that lack attention, their performance is optimal when paired with video prompts and adequate with auditory and light prompts [4,12].

There are three main **task variables** to consider before choosing a prompt: **familiarity** (i.e., familiar or unfamiliar), **complexity** (i.e., easy or complex) and **nature** (i.e., manual or cognitive). Individuals who are unfamiliar with a task are less likely to have verbal labels defining each of its steps. Consequently, auditory prompts, in contrast with visual prompts, are less effective with this type of task [5]. Also, presuming that complex tasks are generally more difficult to label verbally, the use of visual prompts is slightly more effective than auditory. As for the nature of task, due to the reduction of interference, those that are cognitive are more effective with visual prompts while those that are manual are more effective with auditory prompts [9].

4 Guidelines for Using Prompts According to Significant Variables

Based on these facts, it is now possible to propose guidelines indicating which form of prompts to use according to those variables. These guidelines are synthesized in Table 3, which illustrates the efficiency of each form of prompts according to significant individual profiles and task characteristics. As we can see, the efficiency of **verbal prompts** is moderate to effective when used with individuals suffering from Alzheimer's disease, traumatic head injuries and intellectual disabilities [4,9]. Given the great compatibility, they are effective to highly effective with individuals possessing strong verbal abilities [5]. Furthermore, their efficiency for manual tasks is effective to highly effective. **Sound prompts** are moderately effective with individuals suffering from traumatic head injuries. This can be explained by the capacity of these prompts to compensate the attention deficits from these individuals. For the same reason, the content free nature of sound prompts is moderately effective when used with tasks in which individuals lack attention [12]. **Musical prompts**, due to their capacity to compensate attention and motivation deficits, are moderately effective for individuals suffering from intellectual disabilities. For these reasons, they are effective with individuals that inaccurately complete tasks and lack attention. However, given that the information provided is content-free, musical prompts are mostly effective in situations in which the person has a near mastery of the task needing to be done [10]. **Photographic prompts** (iconic or photographic) are usually effective when used with individuals suffering from Alzheimer's disease, traumatic head injuries and intellectual disabilities given that visual abilities generally deteriorate at a slower pace than verbal abilities [4,9]. They are also effective for cognitive tasks [9]. Due to their significant compatibility, the use of photographic prompts with individuals who possess strong visual abilities is effective to highly effective. These prompts are moderate to effective for individuals that inaccurately complete tasks or forget steps and moderate with complex and unfamiliar tasks [4,5]. **Textual prompts**, which require sufficient verbal abilities in order to be successful, are moderate to effective when used with individuals suffering from Alzheimer's disease or traumatic head injuries; effective with those possessing strong verbal abilities and moderately effective for those that lack initiative or forget steps due to their capacity to provide written reminders and detailed instructions [8,12].

Table 3. Prompt efficiency according to significant individual profiles and task characteristics

	Alzheimer's disease	Traumatic head injuries	Intellectual dis-abilities	Strong visual abilities	Strong verbal abilities	Lack of initiative	Forgetfulness' of steps	Inaccurate task completions	Lack of attention	Unfamiliarity with task	Complex tasks	Manual tasks	Cognitive tasks
Verbal	M/E	M/E	M	M	E/ HE	M/E	M/E	I/M	M/E	I	I/M	E/ HE	I
Sound	I/M	M	I/M	M	M	I/M	I/M	I	M	HI	HI/I	M/E	I
Musical	I	I/M	M	M	M	I/M	I	E	E	HI	HI	M/E	I
Photo-graphic	M/E	E	E	E/ HE	M/E	I/M	M/E	M	I/M	M	M	I/M	E
Textual	M	M/E	I/M	M	E	M	M	I/M	I	I	I/M	I	I/M
Video pictorial	E/ HE	E/ HE	E/ HE	E/ HE	E/ HE	E/ HE	E	E	E	E	M/E	M/E	M
Video modeling	E/ HE	HE	HE	HE	E/ HE	E/ HE	E/ HE	E/ HE	E/ HE	E/ HE	E	M/E	M
Light	I/M	I/M	I/M	I/M	I/M	M	I/M	I/M	M	HI	HI/I	I/M	M/E

Legend : HI = highly ineffective; I = ineffective; M = moderate; E = effective; HE = highly effective

Video prompts of a pictorial nature and **modeling prompts** are the most effective prompts in smart homes. This can be explained by their capacity to reinforce desired behaviours while being used; by their capacity to simultaneously use multiple prompts; by their dynamic nature which increase concentration and by their tendency to be the preferred prompt [4]. In addition, by providing instructions in different ways, they can exploit the strengths of almost every individual by accommodating their deficits [6]. As a result, they are moderately to highly effective with every variable seen in table 2. However, modeling prompts, due to increased familiarity and attention, are even more successful than video prompts of a pictorial nature [11]. It can be assumed that **Light prompts**, due to their content free nature, are ineffective to moderate when used with individuals suffering from Alzheimer's disease, traumatic head injuries or intellectual disabilities. However, it can also be presumed that the use of numerous lighting techniques (e.g., flashing) can render these prompts useful for individuals lacking initiative and attention.

5 Experimentations: Validation of the Guidelines

In order to empirically validate the proposed guidelines our multidisciplinary research team designed an experiment, currently in progress, which evaluates prompt efficiency according to individual profiles and task characteristics. The experiment, which began in the fall of 2010 and should end in the summer of 2011, is approved by the ethical committee. Its aim is to evaluate the efficiency of three prompting forms (i.e., verbal, pictorial and video) according to the relative neuropsychological profile (e.g., memory, apraxia, etc.) of individuals suffering from moderate stages of Alzheimer's disease. Several participants have already completed the experiment.

The experimentation is based on a well established cognitive test: the Naturalistic Action Test (NAT). This test is conceived to evaluate the performance of individuals with neurologic afflictions in common kitchen tasks. The NAT used in this experiment is slightly modified in order to better evaluate the performance of the participants. The experimental protocol works as follow: the participant sits in front of a table that has all the items needed for the completion of the task (see figure 1, left). A computer screen and speakers are positioned in front of him. The participant is free to use anything he wants to complete the task and can do so in the order that pleases him. Each trial is recorded on video and timed. When needed, an assistant sitting at the back of the table sends prompts (audio, pictorial or video) by the means of a software application developed purposely for this experiment (see figure 1, right). With a simple click of a button, a chosen form of prompt can be sent to the participant for a specific step. The assistant then notes the results (e.g., type of problem, number of wrong steps, percentage completed, etc.) using the software. It allows the saving of each session separately, with the prompts sent, the timing, the notes, etc.

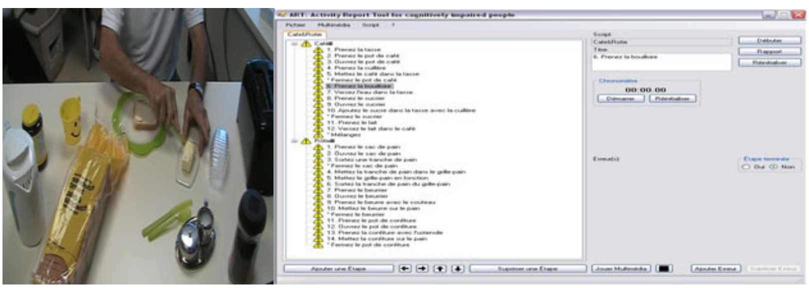

Fig. 1. Ongoing experimentation and developed prompting software

Though the experimentations are not completed, preliminary results indicate that video prompts are the most effective prompts. Auditory prompts seem to be ineffective most of the time while pictorial prompts do not seem to help with the attention deficits of the participants, and thus seem to be also ineffective. Other and more precise results are yet to come.

6 Conclusion

In order for the smart home paradigm to be effective, prompts in these homes will have to compensate the deficits of its users by exploiting their remaining strengths [1,3,6,7,8]. However, predominant use of verbal prompts in smart homes [3], with little knowledge of their effectiveness, affects significantly the efficiency of these technological tools by providing prompts that are not optimized with the profile of its users and the characteristics of the tasks. To contribute solving the issue, we proposed, in this paper, basic guidelines to follow in order to increase prompt efficiency in smart homes. This was accomplished: i) by detailing the type of prompts that can be used in smart homes (see table 1); ii) by presenting major individual and task characteristics that can significantly impact the efficiency of prompts (see table 2); iii) by illustrating thoroughly and synthetically guidelines that indicate which form of prompts to use according to major individual and task characteristics (see table 3) and iv) by describing an experimentation currently in progress in our laboratory which aim to validate the proposed guidelines. Since the literature on prompt efficiency is still in its early stages, the need for further research in regards to prompt technologies, individual profiles and task characteristics is much needed. Therefore, we plan to conduct further experiments that will verify with greater precision the efficiency of each types of prompt according to significant individual profiles and task characteristics. Our work will be beneficial for increasing the compatibility between prompts, tasks and the individuals that use these devices.

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Fall Detection from Depth Map Video Sequences

Caroline Rougier[1], Edouard Auvinet[1], Jacqueline Rousseau[2], Max Mignotte[1], and Jean Meunier[1]

[1] Department of Computer Science and Operations Research (DIRO), University of Montreal, QC, Canada
{rougierc,auvinet,mignotte,meunier}@iro.umontreal.ca
[2] Research Center of the Geriatric Institute, University of Montreal, QC, Canada
jacqueline.rousseau@umontreal.ca

Abstract. Falls are one of the major risks for seniors living alone at home. Computer vision systems, which do not require to wear sensors, offer a new and promising solution for fall detection. In this work, an occlusion robust method is presented based on two features: human centroid height relative to the ground and body velocity. Indeed, the first feature is an efficient solution to detect falls as the vast majority of falls ends on the ground or near the ground. However, this method can fail if the end of the fall is completely occluded behind furniture. Fortunately, these cases can be managed by using the 3D person velocity computed just before the occlusion.

Keywords: fall detection, video surveillance, computer vision, 3D, depth map.

1 Introduction

1.1 Fall Detection Systems

Automatically detecting falls at home has become a major interest in research in these recent years. Indeed, the growing population of seniors in western countries motivates the development of new healthcare systems to ensure the safety of elderly people at home. In particular, for fall detection, different approaches have been explored with three main orientations. The first one is to place wearable sensors on the subject and detect falls with acceleration or rotation information. A detailed survey of this type of methodology is proposed by Noury et *al.* [7]. But these kinds of measure are intrusive in the subject's daily life. External (not wearable) sensors such as floor vibration detectors [1] could be another promising solution in the future but they require a complex setup and are still in their infancy. The other way to detect falls is to use a camera system with computer vision algorithms. For instance, monocular 2D methods were used to analyze the bounding box ratio of the person [11] or the 2D person velocity [6,10]. However, a problem with 2D velocity is that it is higher when the person is near the camera, so that thresholds to discriminate falls from a person sitting down abruptly, for

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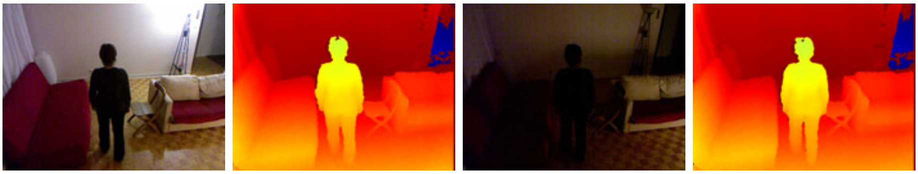
instance, can be difficult to define. This problem was solved using 2D information coupled with calibration data in order to deal with 3D real world coordinates. In this way, Rougier et *al.* [9] obtained the real 3D velocity vector with ellipsoidal head fitting. Another drawback of monocular systems is the management of occlusions. With 3D vision systems, the problem of detecting a falling person occluded by furniture becomes easier to solve. One solution is to reconstruct the total volume information in the scene, for example with a visual hull [2,3], but this is expensive and difficult to set up (multiple calibrated and synchronized cameras are needed). Other works use partial volume information [5] obtained from a Time-of-Flight sensor which returns precise depth images.

1.2 Depth Information

This depth information can be very useful for fall detection as it becomes possible to precisely track the person in the room. A depth image can be obtained with different methods:

- **Stereo vision** [16]. From two views of a scene, a depth image can be reconstructed. However, this type of system needs to be well calibrated and can fail when the scene is not sufficiently textured. Moreover, algorithms for stereo reconstruction are often computationally expensive. Notice that the usual stereo vision system cannot work in low light conditions. In this case, infrared (IR) lights can be added to the system but then, the color information is lost which generates segmentation and matching difficulties.
- **Time-of-Flight (TOF) camera** [17]. A TOF camera provides more accurate depth images than a stereovision system, but it is very expensive and currently limited to low image resolution (e.g. image size of 176x144 pixels in [5]).
- **Structured light**. A depth image cannot be obtained from a video sensor alone, but if a known artificial texture is added to the scene, a depth map can be recovered. This principle is used in the Kinect sensor [15] where an infrared structured light (IR dots) is projected in the scene and observed with an infrared camera. Such systems can acquire bigger images than a TOF camera at a lower price. For example, the Kinect sensor can acquire images with a size of 640x480 pixels at 30 fps, with a cost fifty times cheaper than a TOF camera. The drawback of this system is that depth information is not always well estimated at the boundary of objects and for areas too far from the IR projector.

To develop a low cost and easy-to-install fall detection system, the Kinect sensor [15] is a good solution to obtain depth images. An important advantage is that, with a depth image, the privacy of the person is readily preserved. Moreover, this solution can work day and night because of the use of an infrared sensor. Fig. 1 compares the usual video image with the depth map produced by the Kinect.



With normal light conditions **With low light conditions**

Fig. 1. Comparison of a video image with the corresponding depth map under different light conditions. The Kinect sensor works both day and night thanks to the IR sensor. The depth map blue areas are unreliable (e.g. too far from the projector or some object boundaries).

1.3 Our Method

The centroid height of the person relative to the ground is an efficient method for fall detection [5]. By pursuing this idea, we will simplify this method with several improvements and will demonstrate that a low cost depth map system can efficiently detect falls using this information. While other works need to localize the camera relative to the ground, we will show here that this information is not necessary. Moreover, unlike previous works, we manage the problem of occlusions by using the centroid velocity of the person to detect occluded falls, and we propose to use a training data set to learn the optimal detection thresholds. The different steps of our fall detection system are:

- **Ground plane detection** First, we automatically detect the ground plane of the room using the V-disparity approach which is explained in Section 2.
- **Person tracking and localization** The person is segmented from a depth background image and tracked to recover his/her 3D centroid localization. This step is described in Section 3.
- **Fall detection** The person 3D trajectory is analyzed to discriminate falls from normal activities as described in Section 4. More precisely, the human centroid height relative to the ground is used to detect (not or partially occluded) falls. When the end of an action is totally occluded by furniture, an analysis of the 3D body velocity prior to occlusion allows to detect the fall. Experimental results are shown in Section 5.

2 Ground Plane Detection

To compute the distance between the body centroid and the ground plane, we first need to automatically detect the ground plane in the scene. Once detected, the equation of the ground plane can be recovered and used to compute the distance between a 3D point of the scene and the ground plane.

The RANSAC plane fitting [12] is a commonly used method to fit a plane in the 3D space, but is rather computationally expensive. A recent method, called the V-disparity image [8,13], allows to detect the ground plane more easily with the depth image. Concretely, the V-disparity image consists in computing the

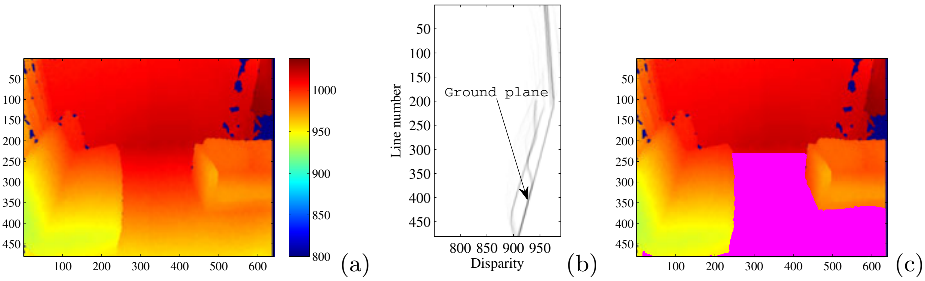


Fig. 2. Ground plane detection: (a) depth image, (b) V-disparity image and (c) ground plane segmentation (in magenta)

histogram of disparity values for each row of the depth image. An example of a V-disparity image is shown in Fig. 2(b). The straight line corresponding to the ground plane can then be extracted using the Hough transform, assuming that the floor represents a sufficiently large part of the scene.

With the V-disparity image and the line corresponding to the ground plane, floor pixels can be detected as shown in Fig. 2(c). From these pixels and their known depths, the 3D plane equation $ax + by + cz + d = 0$ of the ground plane can be recovered. The parameters a, b, c and d can be computed using a least squares fit of the 3D detected points.

3 Person Segmentation and Localization

A commonly used segmentation method for color and gray images [4] is used here to segment moving objects from a background image using depth images. A depth background image B is obtained from N_{train} background images ($N_{train} = 30$ for our experiments). The mean value and standard deviation are computed for each pixel of the image, and used for segmentation. For each pixel (i, j) of the current image I, the pixel is considered as foreground if $|I(i, j) - B(i, j)| \geq T(i, j)$ with the threshold $T(i, j)$ equal to 2 times the pixel standard deviation. Finally, the foreground image is cleaned with morphological filtering and the depth silhouette can be obtained by combining the depth image with the foreground silhouette. The 2D silhouette centroid (x_c, y_c) and the mean silhouette depth d_{mean} are computed respectively from the foreground silhouette and from the depth silhouette. The internal calibration parameters of the Kinect sensor [14], i.e. the focal length of the camera $(f_x, f_y) = (594.2, 591)$ and the coordinates of the principal point $(x_0, y_0) = (339.3, 242.7)$ in pixels, are used to obtain the 3D person localization relative to the camera coordinate system. The 3D silhouette centroid (X_C, Y_C, Z_C) is then obtained by:

$$
\begin{aligned}
X_C &= (x_c - x_0).d_{mean}/f_x \\
Y_C &= (y_c - y_0).d_{mean}/f_y \\
Z_C &= d_{mean}
\end{aligned}
\tag{1}
$$

4 Fall Detection

From a video sequence, the person 3D trajectory is obtained in the camera coordinate system and analyzed to discriminate falls from normal activities. Falls can be detected during the post-fall phase when the person is motionless on the ground just after the fall [7]. The centroid height of the person relative to the ground has been used to detect an abnormal position near the floor [5]. This method works well when the silhouette is not occluded by furniture in the room. In [5], the camera localization relative to the ground was needed. Here this information is not necessary, since we just need to compute the distance from a point (body centroid) to a plane (floor).

4.1 3D Distance From the Ground Plane

The distance from the 3D centroid to the ground plane can directly be obtained by a simple point-plane distance:

$$D = \frac{|aX_c + bY_c + cZ_c + d|}{\sqrt{a^2 + b^2 + c^2}} \tag{2}$$

The distance D can be directly used to check the location of the body relative to the ground when the person is not occluded. However, in case of total occlusion at the end of the fall, this distance can not be computed. As we use only one Kinect per room, an occlusion can happen because of furniture (e.g. sofa) in the scene. In this case, we use another characteristic, the 3D body velocity, to analyze what happened just before the occlusion.

4.2 3D Body Velocity

Another weakness of previous works [5] is that they did not deal with occlusions which is a difficult problem in video surveillance. In this work, a special analysis is done when an occlusion occurs. Indeed, the method based on the height relative to the ground can fail when the person is completely hidden by furniture of the scene like a sofa. Our idea here is to analyze the body velocity, just before the occlusion occurs, to try to guess what happened. The body velocity V was computed as the centroid displacement over a one second period. Generally, V will be lower when a person is doing normal activities than when a person falls. Notice that this criterion is only used in case of occlusion, because in other cases, it can be prone to many false positives, for example when the person brutally sits down in the sofa.

4.3 Automatic Fall Detection

Unlike previous works [5], we investigate an automatic method for fall detection, with a training data set to determine the best thresholds. The training data set was composed of normal activities like walking, sitting down and crouching down, with some occluded activities. The centroid distance from the ground

D_{train} and the 3D body velocity V_{train} were computed in the video sequence. Then, they were used to automatically define two thresholds from the mean value and standard deviation with a 97.5% confidence interval:

$$T_{Dmin} = \overline{D}_{train} - 1.96\ \sigma_{D_{train}} \qquad T_{Vmax} = \overline{V}_{train} + 1.96\ \sigma_{V_{train}} \tag{3}$$

If the body distance from the ground D is lower than T_{Dmin}, then a fall is directly detected. If an occlusion is detected (silhouette which suddenly completely disappears), we search for a high body velocity in the few frames (30 frames = 1 second in our experiments) before the occlusion higher than the threshold T_{Vmax}.

5 Experimental Results

Our fall detection system has been tested on simulated falls and normal activities (like walking, sitting down, crouching down) recorded with a Kinect sensor [15] for a total duration of 4 minutes 9 seconds. With this training data set, the computed detection thresholds were $T_{Dmin} = 35.8\ cm$ and $T_{Vmax} = 0.63\ m/s$. Our fall detection method was validated with a data set composed of 30 sitting down actions, 25 falls including 7 totally occluded, and 24 crouching down actions

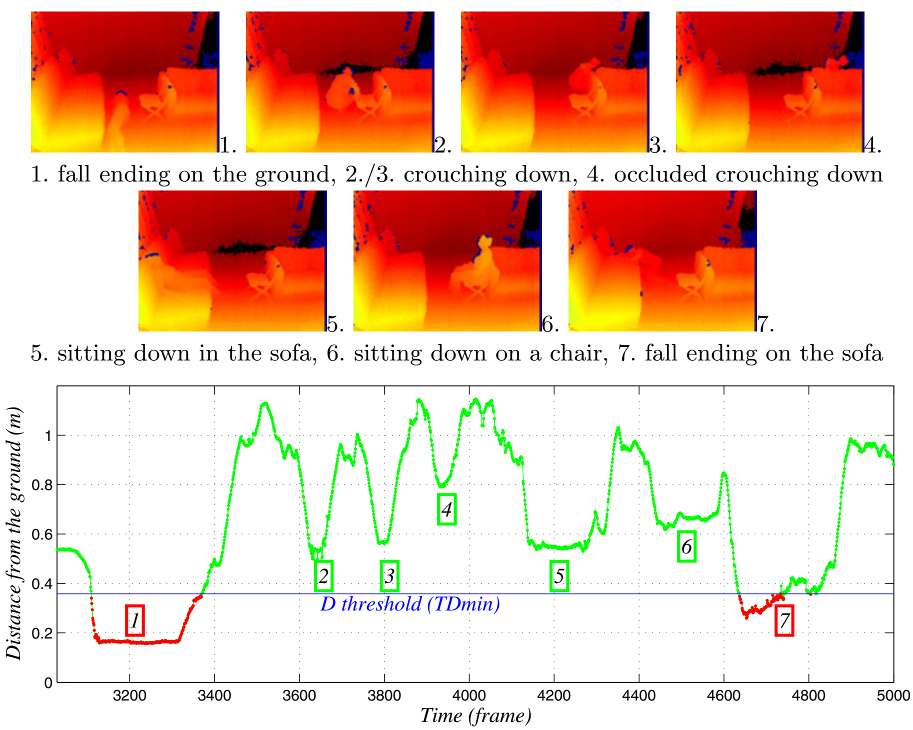


Fig. 3. Distance-from-the-ground curve (bottom) obtained for not or partially occluded events (numbered depth maps above)

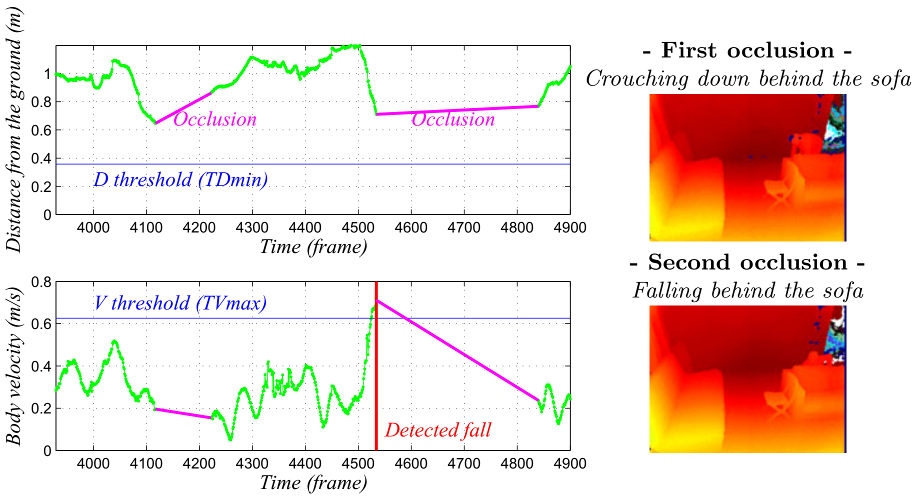


Fig. 4. Distance from the ground and body velocity curves (left) obtained for occluded events (right). The fall is correctly detected with a high body velocity.

including 6 totally occluded, for a total duration of 15 minutes 34 seconds. Some examples are shown in Fig. 3 and 4.

All 'not occluded' events were correctly classified by using the body distance from the ground plane. Even when a fall ended partially on the sofa, the fall was correctly detected as shown in Fig. 3. In case of total occlusion, the body velocity is an interesting method for fall detection, but can be difficult to use to discriminate a fall from a person who brutally sits down in a sofa. Therefore, this feature is only used in case of occlusion to discriminate a fall from a person who crouches down behind a sofa. An example of such cases is shown in Fig. 4. Only one fall was not detected because the person grabbed the sofa, which slowed down the fall, before finishing totally occluded by the sofa at the end. In this case, the body velocity was not sufficient to detect the fall properly.

6 Discussion and Conclusion

When a fall is not occluded, the height relative to the ground is an efficient feature for fall detection as most falls ends on the floor. However, for a system usable in real life, the occlusion problem must be addressed. With a special analysis for occluded events, our fall detection system is also able to detect falls ending totally occluded. Even with cheap depth sensors, our fall detection method gives really good detection results with an overall success rate of 98.7% in our experiments. This solution preserves the privacy of the elderly and can work day or night. For future work, we plan to upgrade the background to avoid 'ghosts' generated by moving objects (e.g. chair) during the segmentation step. Currently, our method is developed with Matlab® which do not provide real-time code, but could easily run in real-time with a C/C++ implementation.

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Smart Silver Towns: Prospects and Challenges

Sung Jun Kim and Bharat Dave

Faculty of Architecture, Building and Planning, The University of Melbourne, Australia
s.kim5@pgrad.unimelb.edu.au, b.dave@unimelb.edu.au

Abstract. An increasingly aging population, information technology developments and shift to high-rise residential neighborhoods combined with lack of aged facilities have led recently to a specific type of residential development in Korea. They appear in the form of silver towns integrated with smart technologies and targeted specifically at the aging population. The silver towns are increasingly being conceived, designed and marketed as smart living environments for the elderly. This paper analyses selected silver towns to obtain insights from the elderly perspective about these developments and understand design challenges for future silver towns and smart technologies.

Keywords: aged living, smart technologies, smart environments, silver towns, technology acceptance.

1 Introduction

In the last three decades, Korea has undergone rapid urbanization coupled with population concentration in high-density urban areas leading to development of high-rise living environments. With one of the fastest increasing aging populations, a number of mutually reinforcing changes have led to development of technology integration in dedicated high-rise living environments for the elderly named *smart silver towns*. This research reports our ongoing analysis of smart silver towns to examine the elderly perception and views about integration and adoption of smart technologies in silver living environments.

2 Rise of Silver Towns

Since 1993, the Korean government developed an invigorating policy to encourage private sectors to invest in a new type of full fee charging seniors living environments referred to as *silver towns*, a unique term for such developments used only in Korea. With emphasis on high-rise and high-density living environments integrated with smart technologies, silver towns are differentiated from 'assisted living' and 'retirement community' with typically low to medium densities in other countries. The rise of silver towns in Korea is underpinned by a number of intersecting forces.

B. Abdulrazak et al. (Eds.): ICOST 2011, LNCS 6719, pp. 129–136, 2011.

2.1 Aging Population

The standard definition of an aged society, according to the Organization for Economic Co-operation and Development (OECD), is between 14 and 20 percent of the elderly of total population of a country. The Korea National Statistical Office (KNSO) data show that whereas France took 115 years to become an aged society, Korea is expected to be an aged society in only 19 years. Moreover, the Korean population of over 65-year olds will lead to a post-aged society with over 20 percent in 2026 and reach about 40 percent by 2050.

Table 1. Aging population trends

	France	United States	Korea
The period being from aging society to aged society	115	71	19
The years of being aged society (14%-20%)	1864-1979	1942-2013,	2000-2019

Viewed differently, the magnitude of change in ‘Aging Index’ (i.e., aging population of over 65-year olds divided by youth population of age 0-14 x 100) shows an upward trend from 47.3 percent in 2005 to 213.8 percent in 2010.

2.2 Family Structure

Since 1990s, extended family structure and changes in patterns of co-residence, i.e., children living with parents, have led to nuclear and independent living. Between 1970s and 1994, the reported shift in rates of co-residence shows a drop from 93 percent to 54 percent within about two decades. It means that the traditional co-residence with a son, especially the eldest son, is now substituted by other trends such as nuclear and single living.

2.3 High-Rise and High-Density Living

Over half of population in 2015 will share the national capital region including Seoul, Incheon and Gyeonggi-do (KNSO, 2007) and it is expected that the trend will continue reaching nearly 54.1 percent in 2030. The housing modernization in Korea started with changes to traditional housing in the form of ‘urban HanOk’ but was interrupted by the Korean War. The construction of ‘Mapo apartment’ complex in 1962 initiated apartment typology leading to high-rise, high-density living environments. A policy of ‘liberalized sale of apartments’ in 1998 boosted supply of apartments and fuelled high-rise living phenomena. By 2005, more than half of population lived in apartments (Gelezeau, 2007).

2.4 Information Technology Infrastructure

Supported by the government’s strategy and infrastructure development plans, the national roll out of information and communication technology (ICT) and broadband Internet infrastructure successfully accelerated Korea’s transition to an information society. Ubiquitous City (U-City) development and u-IT389 plans sum up the vision

Fig. 1. Traditional house (HanOk)

Fig. 2. Mapo Apartment (in 1965)

Fig. 3. Apartment 1990s

Fig. 4. Apartment 2000s

of 21st century's advanced city. These plans are supported also by private industry and reflect new technological and market demands. Various policies and plans such as the "Ten Million People Internet Education" project targeted at housewives and the elderly, "Cyber Building Certificate System" to provide a national standard for buildings with high-speed telecommunications traffic capacity, and "Ubiquitous Dream Hall" to popularize emerging services and technologies, have led to further development and adoption of assistive technologies in silver town developments specifically targeted for the elderly independent living.

3 Related Studies

A number of research studies are reported with a focus on seniors housing, dwellings integrated with smart technology, elderly preference toward smart technology, and technology assisted living in Korea. Some representative references include the following. The transition to high-rise and high-density apartment complexes and urbanization in Korea is examined by Gelezeau (2007) including spatial transformation to apartment living that anticipates current silver towns. Kim and Lee (2007) identified needs of digital network services for future housing development through empirical survey of respondents aged between 45 and 65. Demiris et al. (2004) examined seniors' perception of smart technologies to improve daily lives and monitor health status. Kim et al. (2007) explored when digital technologies support convenient living and health services in aged living environments, and offer opportunities for independent living to the elderly. Jeoung et al. (2006) observed that different types of living environment need different ubiquitous technologies and how technology integration leads to changes in spatial structure of apartment living.

4 Research Questions

The rapid development of ICT-embedded high-rise and high-density living environments brings older adults in continuous contact with assistive technologies and also influences changes in the aged living environment. The primary research focus in our study is *significant patterns in design and use of built environment in silver towns integrated with smart technologies from the elderly perspective.* This research focus is explored by collection and analysis of data as described next.

5 Methodology and Data Collection

Five silver towns built between 1998 and 2007 are chosen as research sites. The selected silver towns are located in the national capital region where about 50 percent of population lives.

Table 2. Selected Silver Towns

	Year	Units	Location	Building
S Tower	1998	144	Seoul	UG 1 ~ G 14
GS Tower	2003	142	Seoul	UG 4 ~ G 15
B Tower	2003	254	Gyeonggi-Do	UG 3 ~ G 8
GH	2006	182	Seoul	UG 3 ~ G 15
GY Tower	2007	419 (104)	Seoul	UG 3 ~ G 15, (UG 1 ~ G 4)

One component of data collection comprised 31 face-to-face interviews with elderly residents aged 65 years and over during August and October 2009. The underlying purpose of interviews was to understand not only awareness and usage of smart technologies but also which smart technologies work or not. Secondly, question and answer type surveys were distributed from which 113 responses were returned between July and August 2009. The purpose of the survey was to identify range of embedded technologies in individual and communal spaces in silver towns. Thirdly, building drawings including site plans, unit plans, and other relevant details were collected from the developers to identify and examine location and purpose of smart technologies introduced in selected silver towns. In addition, semi-structured interviews with developers were conducted to explore rationale for selection and design of smart technologies, their operation and location in silver towns.

6 Sifting Through Data

The following discussion is based on a preliminary analysis of data from selected silver towns with limited focus on technology aspects. It was not very easy to obtain access to and conduct interviews with both the elderly residents and developers because of concerns with privacy of interviewees. In addition, developers were afraid of being identified by others since silver town industry which operates in a highly competitive business environment. Table 3 lists technologies originally planned to be provided, embedded but not activated and technology in operation. Figure 5 illustrates location and features of embedded technology in individual unit in GY Tower.

Table 3. Smart technologies in selected silver towns (Bold: activated technologies)

Location	Categories	Applied Technology
Individual living units	Care	*** Nursing & Emergency call system** *** Movement detection sensor** *** Portable emergency pager** * Real-time health check system * Tracking system
	Environment Control	*** Remote Inspection** * Indoor air quality control system **(only air supply system)** * Home network system * Light control / Energy saving system * Elevator call system
	Security	*** Cardkey** * Monitoring system
Communal facilities	-	*** CCTV** * Movement detection sensor * Parking control

The spatial analysis of silver town unit plans shows increasing choice in units plans in more recently developed silver towns. In terms of representative unit plan size, S tower development in 1998 offered units of 49.6 m^2 whereas GS tower built in early 2003 offered units of 119 m^2 areas. It indicates that choice in unit areas has expanded over time. At the same time, there do not appear to be many significant differences in assistive technologies between the early and later silver towns.

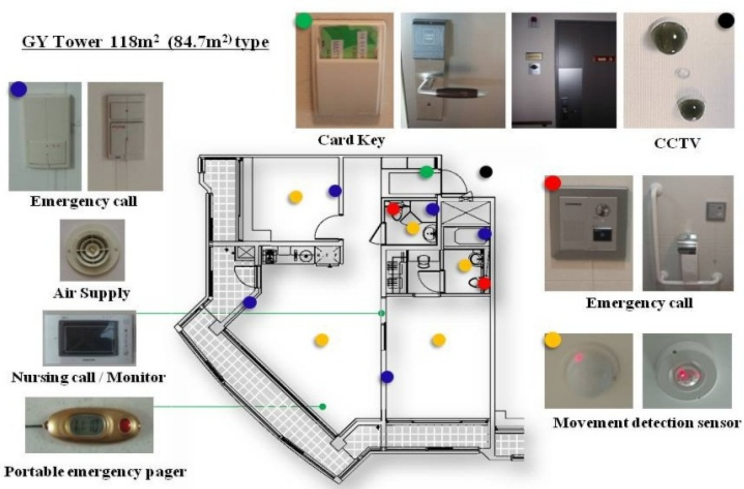

Fig. 5. Assistive technologies in silver town unit (GY Tower 118 m^2 type)

The quantitative analysis of survery data indicates some interesting correlations. For example, the elderly living period and the building age reflect a consistent pattern in silver towns examined. The average age of 75 years suggests that residents tend to move into silver towns when they were in late 60s. Hence silver towns appear to be perceived and accepted as long term and stable living commitments. That, in turn, may require long term operational stability in assistive technologies that residents get used to over time and discourage incremental or subsequent changes.

Table 4. Silver towns and age of residents

	S tower	GS tower	B Tower	GH	GY tower	5 towns
Facility built	1998	Early 2003	Late 2003	2006	2007	
Average Time Occupied (Month)	87.2	61.2	56.5	24.7	15.7	41.6
Average age	3.52	4.29	4.0	3.83	3.55	3.75

* Average age: 3 (71~75), 4 (76~80), 5 (81~85)

The qualitative analysis of interview data suggests that residents are technology savvy and use various combinations of mobile telephony and computer for the Internet. For example, the interview subjects GS3 and GS2 regularly use the Internet as a communication tool to talk to children and grand children living in the USA.

Among the technologies embedded in silver towns, most recognition and significance is attached by elderly to health and safety related technologies. However there appears some mismatch between the designed and actual functionalities of technologies. For example, real-time health check system to monitor health via online connections between residents and doctors is misunderstood by most interviewees due to the difficult technical terminology involved in its use and confusion with the general examinations conducted twice a year at a hospital directly connected to the silver town. The interview with developers revealed that the system was installed in the beginning but it is not operational due to complicated instructions in routine use.

Nursing and emergency call system appeared as the most needed technology in silver towns even if the elderly residents may not have used it before. The system is typically embedded in bedrooms, living room and bathrooms to respond to unpredictable medical emergencies. Although some people confused embedded emergency call system with portable emergency pager, most residents could indicate locations and instructions for emergency call systems. There were also some concerns about features of the system. For example, GS4 said: "*I tied a knot to the string or hide it behind sofa because it is too sensitive and it can be easily pulled on so I try to be careful with it*". GS3 mentioned that it can inadvertently raise alarm and medical attention by kids accidently pulling the string.

Portable emergency pager generated the most reactions among the elderly residents but it is still indicated as an essential technology in silver towns. For example, B3 was surprised that he did not even think about it when he first came to silver town however he thought the size of pager was very small. On the other hand, many seniors feel healthy enough and do not carry it on person. GS3 mentioned: "*It is bothersome. If I feel a little off or have a disease, I would carry it but I think I am ok and the possibility that my wife and I are in serious trouble at the same time would be low*". GS2 did not consider it necessary to carry emergency pager all the time and instead brought up the likelihood of dead battery as a potential drawback. The residents need to individually remember to charge battery which poses a potential problem. GS3 changed battery a couple of times in the last 6 years but there is no visible feedback about battery status. GS4 noted that "*nurses were informed at the beginning of two to three years but since these [last] couple of years there is no response [i.e. reminder]*". Surprisingly, some of residents returned the pager to nursing unit since it was not found useful enough. To inform and encourage the elderly to carry and use emergency pager and other systems, B3 suggested repetitive education whereas another resident proposed alternative designs such as bracelet or button type.

Some residents misunderstood the tracking system as movement detection sensor and others misunderstood it as a form of portable emergency pager. However, tracking system is generally not applied in silver town by developers.

CCTVs cover approximately 90 percent of communal spaces and the residents appear well aware of its presence. On the other hand, CCTVs provided in individual units in S Tower to closely watch residents needing frequent assistance or long-term care were deactivated due to privacy concerns.

The functionality of cardkey system was well understood and also the fact that it included an additional function such as energy saving was recognized because it could cut electricity supply. Moreover, it could indicate the residents' in and out status at reception desk by connected computer program. It was selected as one of the most useful technologies in aged living facility.

There were no substantial changes in living patterns due to technology use from the elderly perspective. However, the residents were aware of purpose and intention of some technologies which extends the potential reach of daily contacts and interaction among the elderly.

7 Design Challenges

The preliminary analysis of data from just selected silver town sites has identified a number of intersecting issues about assistive technologies and their relationships with design of spatial environments in silver towns. We have articulated these issues at some length elsewhere (Kim and Dave, 2010) and briefly reiterate below.

- *Acceptance* of technology needs both tangible benefits and periodic reinforcement.
- *Misappropriation* arises when users project additional functionalities on a particular technology or device.
- *Avoidance* in use of technology may spring from significant amount of effort involved to carry or activate one.
- *Dependability* refers to the extent to which devices and technologies need to provide constant feedback about their operational state.
- *Control* or the perception of control over technology is desirable in order to modulate or override technologies.

8 Future Work

This paper briefly reported our research based on preliminary analysis of data from selected silver towns. The spatial, quantitative and qualitative analysis of collected data as described here is hoped to generate composite answers to research questions posed earlier. These insights, in turn, are intended to inform qualitatively better design of spatial layouts and their integration with smart technologies in future silver towns.

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Interdisciplinary Design of an Electronic Organizer for Persons with Alzheimer's Disease

Hélène Imbeault[1], Hélène Pigot[2], Nathalie Bier[3], Lise Gagnon[1], Nicolas Marcotte[2], Sylvain Giroux[2], and Tamas Fülöp[1]

[1] CDRV/CSSS-IUGS & Université de Sherbrooke, QC, Canada
Helene.Imbeault@USherbrooke.ca
[2] Laboratoire DOMUS, Université de Sherbrooke, QC, Canada
[3] Université de Montréal, QC, Canada

Abstract. Because of cognitive problems, it is very difficult for individuals with Alzheimer's disease (AD) to manage their time. Consequently, they are dependent on their caregivers or use pen-and-paper organizers, both of which have limitations. A more interesting alternative could be an electronic organizer that optimizes the functional autonomy of persons with AD. This article describes the development of an electronic organizer called AP@LZ by an interdisciplinary team of computer specialists and clinicians. The results show how knowledge of technology and knowledge of the cognitive capacities of persons with AD can be combined. A pre-experimental phase confirmed that AP@LZ was easy to use by elderly participants.

Keywords: Alzheimer's disease, memory deficits, electronic organizer, compensatory memory device, interdisciplinary approach.

1 Introduction

Memory deficits are central to Alzheimer's disease (AD). One of the first signs of AD is the difficulty remembering recent events [1]. For example, individuals with AD may forget what they did the day before. They may also have difficulty remembering tasks to be done at a specific time in the future, which involves prospective memory [2]. For example, they will forget to buy milk after their doctor's appointment even though they pass a grocery store. Consequently, they have difficulties in scheduling activities and appointments.

The integration of any type of device in daily life to compensate for cognitive problems in AD depends on the person's ability to learn how to use it. Some studies, employing conventional aids such as calendars, to-do lists and pen-and-paper organizers [3, 4], used errorless learning methods that promote preserved learning mechanisms in AD, such as procedural memory. They all found that persons with AD can learn to use these aids independently. Although some studies have shown some benefits of using pen-and-paper organizers in AD [5, 6], these organizers can have limitations: persons with AD may feel stigmatized, they may have difficulties in updating information or they may write notes that are incomplete or illegible. Also, pen-and-paper organizers are not interactive: they do not have automatic reminders and the

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person must remember to check them at the right time. The disadvantages of pen-and-paper organizers could easily be addressed by using existing electronic organizers that have many integrated features, such as a phone and a reminder. In addition, electronic organizers are being used increasingly and successfully with individuals with cognitive disorders, such as people with traumatic brain injury [7], multiple sclerosis [8], mild cognitive disorders [9] or schizophrenia [10].

Very few studies have looked at the use of electronic aids by persons with AD. One of these aids, the pager NeuroPage [11] reminds people of appointments or things they must do. NeuroPage vibrates (or beeps) and the name of the activity or scheduled appointment appears on the screen. According to Wilson, Emslie, Quirk, and Evans [12], NeuroPage can be used by people with degenerative diseases such as multiple sclerosis or AD. Although interesting, the NeuroPage system can only handle short messages. In addition, users with vision problems (common in older adults) may have difficulty reading the messages because of the small display. Finally, the service that sends the reminders of appointments and activities must be informed of them at least two days in advance. Users are thus dependent on this remote service, which can be a limitation.

Oriani and collaborators [13] studied the use of an electronic memory aid (voice recorder) by five persons with AD. The participants were asked to do seven activities, described in a recorded message, when an alarm went off. The results suggest that this type of aid is effective but for very simple preprogrammed activities in an experimental context (e.g. leave the room). Szymkowiak et al. [14] explored the usefulness of a simple interface specially designed for personal digital assistants (PDA). The interface comprised mainly two functions: consultation and registration of diary information and appointments. The PDA was used in their daily lives by five individuals between the ages of 34 and 93 with different degenerative diseases. Unfortunately, no information is given regarding the types of degenerative diseases or if the participants used their PDA efficiently in their daily lives.

In conclusion, electronic memory aids have significant potential in fostering the autonomy of persons with AD. However, most of the electronic assistants need a remote center or caregivers to register appointments and activities. Also, commercial memory aids that include electronic organizers appear too complex to be used by persons with AD. Their interfaces display a lot of information and it takes several steps to enter appointments. The first objective of this study was thus to create an electronic organizer interface tailored to the capacities of persons with AD (conceptual phase). The interface had to be very simple and allow the users to register their activities and appointments by themselves, without the help of a remote center or caregiver. The second objective was to pretest the interface with elderly participants to explore if it was easy to use (pre-experimental phase).

2 Conceptual Phase

2.1 Method

To ensure that the organizer met the users' needs, it was developed using a user-centered design (UCD) [15]. In this case the users are persons with AD. The conception phase was done with the help of secondary users, namely two neuropsychologists and an occupational therapist (clinicians) with expertise in the cognitive assessment and rehabilitation of persons with AD. Two main reasons justify this approach. First, elders with AD lack introspection and are therefore unable to express their needs and difficulties encountered in their daily lives and with assistive devices, either pen-and-paper or electronic organizers. Second, people with AD experience stress when facing adverse situations that place too much demand on their cognitive functions. Thus it was more feasible to design the organizer with clinicians who are able to express their needs and then to validate the interfaces with the end users.

In three preliminary working sessions, the computer specialists and clinicians determined the specifications based on the needs of clients observed in clinical settings. The computer specialists proposed various assistive devices to help people with AD to organize their daily lives, such as MOBUS. This previous electronic organizer was developed for adults with schizophrenia or head injury by the DOMUS laboratory [16]. It was designed to help users to remember appointments and activities, and to notify their caregivers when these activities are done. The planned activities are registered by the caregivers.

The researchers decided to pinpoint the MOBUS functionalities and the simplified interfaces that could be used by persons with AD. New sections were added, such as personal and medical information and a photograph album to help with reminiscence. A priority was to limit the functionalities to make the device easy to use but also to allow extensions in the future. Thus the use of contextual information was deliberately eliminated. The main change for the new organizer was to enable persons with AD to use the organizer without the assistance of their caregiver. The MOBUS client server architecture needed to set up the link between user and caregiver was eliminated. Finally, smart phone models were chosen on the basis of specific characteristics such as a touch screen and a large display.

Subsequently the clinicians and computer specialists met 18 times (over a five-month period) to develop the new prototype of the organizer called AP@LZ. The UCD method was applied by iteratively presenting preliminary versions of the organizer interfaces until agreeing on a solution that satisfied the clinicians. One of the main challenges was the choice of functions to schedule appointments and activities (e.g., how to register activities, alert users of an upcoming activity, manage occurrences, change appointments already registered). Another major challenge was the depth of information processing. The depth, which means the steps to go through in various screens to schedule an appointment or find information in the organizer, had to be minimized so that individuals with AD would not lose track of the purpose of what they were doing when using AP@LZ. Compromises had to be made between information that had to be available and information that could be displayed on the screen, the choice of words and icons, the buttons' place, and the size of the screen.

2.2 Results

At the end of the design phase, it was decided that persons with AD should have six basic functionalities available on a smart phone, according to their cognitive difficulties and their needs in daily living. The main functionality of AP@LZ, i.e., reminder of appointments and activities, comes up automatically on the home page when the smart phone is turned on. It shows the time, date and day of the week (Figure 1.a). Users can view what they did yesterday or what they have to do tomorrow by selecting the arrows at the top of the screen. The other five functionalities are accessible from the AP@LZ home page: 1) *Appointments* contains a list of pre-entered personalized activities and their location. Users select the activity, date and time, and indicate if they wish to be reminded 1 hour and/or 24 hours in advance (Figure 1.b). At the time of the appointment or activity, the organizer beeps and a message appears on the screen until the person reacts and pushes a specific button; 2) *Personal* contains the person's name, address and phone number; it also includes a "photos" option where recent or older photos are displayed like a slideshow (Figure 1.c); 3) *Medical* contains the person's medical history and list of medications; 4) *Contacts* brings up a list of people to call (Figure 1.d); to call a contact, the user simply selects the name; and 5) *Notepad* can be used to enter different types of information such as a grocery list. A functional version of AP@LZ was installed under J2ME for a smart phone with integrated Global Positioning System. The AP@LZ application operates in standalone mode so that users are completely independent and do not have to be connected to a remote service.

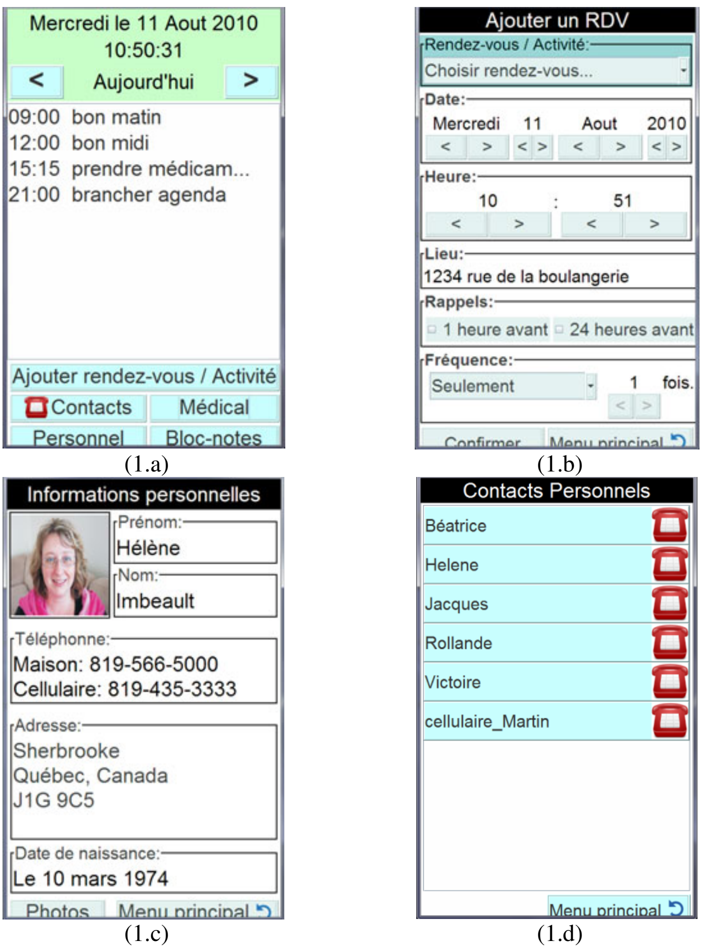

Fig. 1. AP@LZ screens: 1.a Home page, 1.b Appointments, 1.c Personal, 1.d Contacts

3 Pre-experimental Phase: AP@LZ Used by Elderly Participants

3.1 Method

Participants. To test AP@LZ, two users over 70 years of age participated in a pre-experimental phase. This first phase ensured that the interfaces demonstrate usability characteristics for elders. It helped to get feedback during this initial stage, where the elders could express their feelings about the drawbacks and advantages of the organizer. It is expected that if the elders without AD need a long time to learn AP@LZ, people with AD will not be able to use it.

The two elderly participants reported forgetting a few minor things that had no significant impact on functional independence and did not met AD criteria, as shown by their scores on the Mini-Mental State Examination (cutoff = 25 based on age and education) [17, 18] and the Mattis Dementia Rating Scale (cutoff = 123) [19] (see Table 1).

Table 1. Participants' demographic characteristics and general cognitive functioning

	Participant 1 (P1)	Participant 2 (P2)
Age (years)	74	72
Gender	Male	Male
Education (years)	9	15
MMSE	27/30	28/30
DRS	133/144	134/144

MMSE: Mini-Mental State Examination [18]; DRS: Mattis Dementia Rating Scale [19]

Procedure. Participants used AP@LZ in their daily lives for 12 to 18 days and were asked to report any problems they had with the organizer (for example, if it stopped working). Their use was also tested objectively in individual meetings. In the first two sessions, the participants had to answer fifteen specific questions, such as "What do you have to do to enter an appointment in your organizer?" In sessions 3 and 4, the participants had to do five role-playing exercises in each session, such as simulate an appointment with the doctor. The participants' performance was scored on a 4-point scale (see Table 2) for a maximum of 20 points per session.

Table 2. Scoring scale for performance when using the organizer

0	Nothing done or error in the functionality choice AND incorrect information registered
1	Needs a cue for the functionality choice AND the information content
2	Needs a cue for the functionality choice OR the information content
3	Selects the appropriate functionality but needs a light cue to register the information content OR needs a light cue for the functionality choice but registers the appropriate content.
4	Correct information registered in the appropriate functionality

The fifth and final session involved five "real-life" activities. For example, the experimenter called the participants on the smart phone to make an appointment. The same scoring scale was used for the real-life activities (see Table 2). The specific questions, role-playing and real-life activities were used to objectively rate how older adults interacted with the AP@LZ organizer, what difficulties they encountered and how these difficulties could be avoided.

3.2 Results

Participant P1 used AP@LZ first, so that adjustments resulting from his experimentation could be tested by the second participant (P2). During these five sessions, the participants' success rate varied between 73% and 100% (Figure 2). According to Nielsen's criteria [20], it was confirmed that the application was easy to learn because, from the very first session, both participants learned the main functions of AP@LZ. They were able to extract information from the organizer, such as previous activities, the day's appointments, list of medications and medical history. The second session showed that the application usage was easy to remember (another Nielsen criterion) since once again both participants had a high success rate using AP@LZ. In subsequent sessions, the level of difficulty was different since the participants were asked to role-play in the experimenter's office. In sessions 3 and 4, participant P1 had more difficulties than participant P2. One of these difficulties was navigating between the screens to add new activities to the personalized list ("Add appointment/Activity" functionality). After making a change, navigation was easier, which was confirmed by the higher success rate of participant P2 using AP@LZ with the modification.

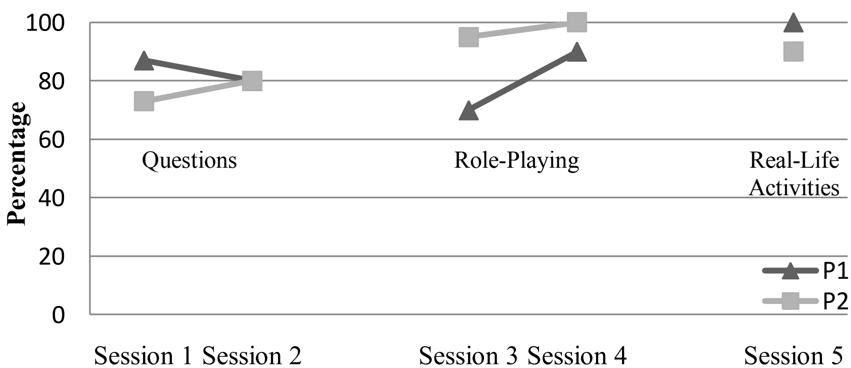

Fig. 2. Results obtained on each session by the two participants

During the real-life activities, the participants were able to phone the experimenter at the scheduled time, enter an appointment spontaneously and receive calls.

By the end of the test period in their daily lives, the participants found the AP@LZ application easy to use and intuitive. For example, one of the participants added a medication to his list (Medical section) without a previous learning session. Both participants liked using the arrows shown on many of the screens. During the design phase, an effort was made to keep the arrows consistent throughout the interface. The participants also found the Contacts section easier to use than on their own mobile phone since the phone contacts were previously registered.

4 Conclusion

The AP@LZ organizer was designed to be easy and pleasant to use by people who are not familiar with the latest technology and have significant cognitive problems, such as in AD. To ensure the prototype was adapted to the target population, we used a UCD method and interdisciplinary approach combining the knowledge of researchers and specialists in computer science, occupational therapy and neuropsychology.

AP@LZ was developed at the DOMUS laboratory from an existing model called MOBUS. Various functionalities were added for AP@LZ. The main challenge was to create an interface that would enable persons with AD to register their appointments and activities by themselves, without any help. We therefore decided to include a list of preprogrammed personalized activities. Thus, the completion of the information needed for specifying an appointment (date, time and place) requires only one AP@LZ screen, allowing the person with AD to register the appointment in one step. We also stressed the importance of reducing the depth necessary to interact with the electronic organizer and limit the amount of information displayed on the screen. Homogeneity in the language and symbols used also facilitates the learning process. We chose a smart phone with a large screen so that the messages could be more detailed yet still legible for older adults. Unlike the device used by Szymkowiak and colleagues [14], AP@LZ provides a variety of functions including a slideshow of recent and older personal photos. The Contacts functionality is also a safety feature since older adults can use it to call for help if necessary.

By the end of the pre-experimental phase with the help of two elderly participants, we were able to stabilize AP@LZ and demonstrate its usability for elders. The next step is to test AP@LZ with persons suffering from AD, which is currently being done. Many challenges, such as the importance of memory problems and apathy in AD, will have to be addressed in these future studies to ensure that AP@LZ will be correctly learned and used by this population. However, AP@LZ is promising and opens up new rehabilitation possibilities in dementia.

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From Individual Communication to Social Networks: Evolution of a Technical Platform for the Elderly

Cécile Bothorel[1], Christophe Lohr[1], André Thépaut[1], Fabrice Bonnaud[2], and Gilbert Cabasse[2]

[1] Telecom Bretagne, UMR CNRS 3192 Lab-STICC, Technopôle Brest-Iroise CS 83818, F-29238 Brest Cedex 3, France
firstname.lastname@telecom-bretagne.eu

[2] Alcatel-Lucent - Application Software Group - R&D, 8 bis, rue de Kervezennec - CS 82802, F-29228 Brest Cedex 2, France
firstname.lastname@alcatel-lucent.com

Abstract. One of the biggest challenges we currently face is to keep elderly people immersed in their social environment when they leave their home and enter a retirement home. Many of them feel isolated. The TV stands as their favorite media, and our first experiments showed that listening to vocalized local news and receiving TV messages and photos from family helped in fighting these feelings of isolation. With online social networks, we wish to involve the elderly in new types of interactions, more various and frequent. They will be more active and included in micro-conversations around multimedia contents. The retirement homes will benefit also from social networking capabilities. They will participate to the local news dedicated to the elderly people. In addition, the remote family will be informed of activities through an agenda and various publications.

Keywords: Social Ties; Social Networks; Digital Life; Assistive Technology to Improve Quality of Life and Health for Seniors and their Caregivers; Platforms, Middleware and Software Architectures for Seniors; Real World Deployments and Experimentations in Smart Houses, Hospitals & Living communities.

1 Introduction

The aging population is a very strong concern in Western countries. The significant increase in life expectancy leads to worry about increasing the quality of life of seniors. On the other hand, there is a strong link between aging and loneliness. This sentiment characterizes persons who do not communicate with their family and immediate friends, and whose number of social contacts decreased significantly. According to French statistics[1], 74% of elderly people in France say they are suffering from loneliness.

[1] From the group "Combattre la solitude" (Fight loneliness) which includes many associations and the Fondation de France

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If several other factors reinforce this feeling of loneliness (physical disabilities that limit the territory of life of elderly, loss of spouse, etc.) [7], the loss of a social network is especially noticed. This phenomenon is observed when work colleagues are encountered less often, when friends are more remote or die, when family visits are becoming less frequent. Several studies [4] show that the loss of a spouse (only one in five seniors lives together as a couple) also accelerates social isolation. Finally it is estimated that currently one quarter of residents in nursing homes might not suffer from physical dependence or psychological dependence, but from social dependence. Through technical platforms suitable and customizable, our multidisciplinary research team aims at improving the lives of the elderly living in retirement homes by preserving, enhancing, or creating social ties. Digital innovation is a huge issue nowadays to enhance the quality of life, autonomy or social life for elderly [8].

TV-Kiosk[2], very similar to our project, uses a simple Internet service, where "elderly can now stay in touch with their family and friends and get easy access to information provided by the care centre they life in. [...] A small-scale field trial is ongoing". Related works are still new studies, and eHealth *techno-enthusiasts* have still to evaluate socio-technical factors to maximise the likelihood of successful implementation and adoption [2].

Through the AIPA project (2007-2010)[3], we propose a TV-based service that allows elderly people living in nursing homes to be connected to their network of contacts. The project team has chosen to involve several players (seniors, families, professionals of the nursing home, retired volunteers, neighbourhood town hall, etc.) since the beginning of the design process. Sociologists have conducted individual and group interviews and have identified two types of services: the elderly receive emails, pictures, videos from their relatives, and also local news and obituaries from the regional daily press [3].

Sociologists also recruited 11 elderly people (aged 59 to 92, median age is 87), and their 65 relatives. These people have experimented the service for about a year. 3 of them did not much use it; 4 gave up. The 4 daily active participants were mostly people in good health with few visits from the caregivers. They were elderly people less visited by their family but with a strong emotional network and they enjoyed particularly getting news from their family through AIPA mediated services. While most of the users have shown a real interest, they expressed some suggestions for improvement. The *socially active* users felt a frustration because of their position as consumers; they asked for more active functionalities such as the capability to respond to the messages or comment on pictures sent by their relatives. *Emotionally isolated* people or people whose family was minimally involved, showed less enthusiasm for AIPA since the proposed contents were essentially social. The the other contents were much poorer. They asked for thematical contents or contents related to their hobbies.

[2] `http://www.smartcareplatform.eu/content/tv-kiosk`

[3] Companymages/AIPA Project Home Page. `https://www.companymages.eu`, last visited January 2011.

2 Social Networks and New Challenges for Isolated People

2.1 Strengthen and Rediscover Relationships

Social studies show that virtual friendships are mostly the prolongation of real life ones. In general, people who interact in their virtual life also interact in their real life [6] [5]. People involved in many social activities will be very active online. We think in our current project Mazadoo that with new networking possibilities in AIPA-like systems we could interest such socially active old people. Beyond this standard behaviour, we find people who make new connections on the web before meeting in real life. For those individuals the aim of being online is first to share interests, passions, and not to extend their network just to extend it as a primary objective [6]. The emotionally isolated people identified in the AIPA study may be candidates to share knowledge, stories, passions, etc and maybe rediscover relationships through mediated networking.

We cannot talk about online social networks without focusing on Facebook usage. [1] observed that even if the average number of friends is around 130, most people interact regularly with 4 to 6 people. These few friends are considered as *strong ties* and are mostly people we meet often in real life. Social networks have changed some aspects of our *weak tie* relationships. Weak ties are unfrequent relationships with known people, such as old school mates. “In the past we would have to meet or phone them to catch up. Now, the social networks open an easy route to reconnect to them. Via newsfeeds and their wall, we can get back in touch in a lightweight manner. Although weak ties are much bigger in number, communication with them is unfrequent”.

By introducing Social Networking Platforms (SNP) in our project, we aim at strengthening existing and close relationships for high sociable people, but also rediscover weak ties and develop hobby-oriented ties especially for those who feel isolated and are not involved in a real-life dense network. For the first ones, the web2.0 networking tools will bring a lot of (maybe light but frequent) exchanges; for the second ones, the tools will open the opportunity to create links with 'old' relationships or 'new' ones in relation with centres of interest.

2.2 From Point-to-Point Messaging to Community Interactions

In AIPA, family (and acquaintances) shared emails and photos through a dedicated service developed for this purpose in the project. Each member of the family shared his/her content with one older people. The elderly is the recipient, the family is the sender, with no mediated-interaction around a photo. But the elderly, as a matter of fact (see previous section), is asking conversing about a photo, about a message or about a video.

The contextual comments to a content is one of the signatures of SNPs. The publication of a photo (and its legend) becomes the scene of real feeds of reactions. People don't *send* content anymore as an attachment, but now *publish* them to a public (the public may be constrained and limited to a few *friends*). As blog posts, those publications are now a way to bring together people who interact as micro- and transient-communities; incidentally we observed that the published content becomes sometimes more an opportunity to meet friends than to collect comments about it.

Social networking appears as an interesting opportunity to keep elderly people involved in social interactions. Just like casual discussions at the baker's or when walking to the marketplace, social networking allows frequent, light and collective discussions with close family, but also with other people commenting on a photo or a web link.

3 Mazadoo: A Social Network to Connect Elderly People

The dedicated service provided by AIPA is quite simple to use, but the family has to subscribe, manage new credentials, upload their photos to this dedicated site, etc. It's expensive and time-consuming to manage several image repositories.

Now, with the SNPs, e.g. Facebook, those sharing activities are easy and popular. In Mazadoo, we make the hypothesis that most relatives involved in our experiments will know and be regular users of social medias. We find that at the very first stage of the experiments, they actually are using Facebook. We hope that they will more easily and more often interact with their elderly family. We also hope that new participants will naturally become involved (nieces, cousins, grand-children, etc.).

3.1 Why is Mazadoo Using Facebook?

The aim of Mazadoo is to offer a link between people using a social network to communicate (with the computer interface proposed by the social network editor) and elderly people, who should be able to receive and respond from the social network, but using the Mazadoo TV interface. From the standpoint of the elderly, the underlying SNP is transparent. In fact, Mazadoo could be interfaced with any SNP.

Why the choice of Facebook against the competitors (Google, Twitter...)? From a technical point of view, the SNP must provide an open API in order for the Mazadoo platform to retrieve the interactions (messages, pictures, videos...) posted by the external users and inversely insert new interactions toward relatives on behalf of the elderly. The SNP should preferably offer a single tool to the relatives to support multiple interaction types (text, picture, video): send a private interaction to the elderly (like an email), send an interaction to a group of friends, including the elderly (like when you post on your Facebook wall), allow the friends to add comments to the contributions from others and provide some calendar functionalities (send an appointment to the elderly). The access to the SNP should be free, at least for the relatives. The SNP should also preferably be already known - and used - by a large audience of relatives. This indeed increases the possibility to get support from other relatives (children...), and thus accelerating the learning curve for using that platform. Retirement homes may also use the same SNP to communicate with the general public (and thus include the elderly, their relatives, and any external people interested in the activities), via a global page for the retirement home information.

Facebook is currently the only platform to respond positively to all those considerations. This also overcomes the only drawback of Facebook: its bad reputation about privacy disclosure. This reputation is based on cases that happened with Facebook accounts that are using the default privacy settings, which allow strangers to see your contributions. Mazadoo creates the Facebook accounts on behalf of the elderly, and tunes the privacy settings so that only friends can see their contributions. We gave courses to educate the family on these settings.

But Facebook is also THE social network: when you speak of social networks, the first platform that comes to mind is Facebook. Plugging Mazadoo into the favorite network of the end users makes it immediately usable by 600 million users worldwide. This predominent position of Facebook in the social networks also allows Mazadoo the benefit of a new information media: the Facebook pages. Facebook contains millions of pages about specific subjects that can be in the interests of the elderly: their favorite soap opera, their native village, a club for their hobby, the sport club or the school of their grandchildren, etc. This feature brings potential news hobbies to the ederly (not possible within AIPA).

3.2 The Services Provided by Mazadoo

These services can be split into two categories: personal services, provided in the room of the resident; and common services for all the residents of the retirement home such as common activities proposed by the coordinator of socio-cultural activities.

Individual Services. Using the remote control of the TV, the elderly channel-flicks to the Mazadoo channel. This is a personal channel that provides, like a Facebook newsfeed, in a single screen, an adapted access to a set of services: messages from relatives, photo/video sharing from Facebook friends; reminders of activities proposed in the retirement home, via an interactive agenda from the retirement home Facebook page; a daily selection of videos, pictures and articles from local press (The Telegramme, a regional newspaper); and, in the near future, contents about their hobbies from Facebook pages.

Communication via social network friends. The elderly person have a personal Facebook account. Relatives, as *friends*, benefit from all the usual Facebook features to communicate to the elderly : sharing status, pictures, videos (except links that cannot be adapted to Mazadoo); sending messages to all their friends including the elderly or private message to the elderly only. These interactions can be performed on a nomadic mode from anywhere (browser, smartphone). Some people (in particular teenagers) say that they never share with their parents or grand-parents what they share with their Facebook friends. This restriction is also true between private life and professional life. This multiple profile management is one of the issues we are working on.

Fig. 1. Facebook news feed on TV

Adaptation. Obviously, the native Facebook web page cannot be read by the elderly on their TV screen. Mazadoo ergonomists and sociologists work with a representative panel of users to define the most adapted display of Facebook newsfeeds and content consultation. When the elderly channel-flicks to their Mazadoo channel, an adapted display of the newsfeed of her/his Facebook account, enriched with private messages, is provided. This homepage (Fig.1) lists the latest received messages, pictures or videos, prefixed with the sender's profile picture. Because a TV screen is not adapted for the elderly to read a long text, all textual contents such as messages, comments or articles are vocalized (read by the TV through the Text-To-Speech technology).

Interaction. The elderly are not passive when receiving messages, pictures or videos. They can select the *Like this* button with the remote control. This action updates the Facebook content by adding the elderly to the list of people who like this item. For more interaction, the elderly can respond/comment by using the telephone to record a voice mail. By selecting the *Respond* button with the remote control, the phone rings and proposes to record a voice mail. The voice mail is seen as a link to an audio file and inserted as a comment to the original Facebook content.

Common services. One requirement of a retirement home is to provide visibility on their services (e.g. activities, meal menus) to visitors but also to remote family who are often also the payer. To fit this need, a Facebook page for the retirement home has been created: it compiles pictures and testimonies of activities, agenda for future events, comments, questions, etc. It can be consulted by people who say they *fan*.

Considering this agenda, Mazadoo enriched Facebook by providing to the retirement home coordinator the record of a reminder of an activity. This reminder is a voice message that is played to residents minutes before the activity. The phone rings and the message is played. A TV screen in the welcome hall of the retirement home displays a mosaic of contents automatically when dynamically extracted from the retirement home Facebook page. Visitors and residents have access to up-to-date meal menus, upcoming activities, pictures from previous events, etc.

3.3 Experimentation

Technical aspects. The Mazadoo architecture is based on cloud computing. Mazadoo services are provided by software running on servers, called the Mazadoo platform, hosted on the ImaginLab[4] data center. To minimize the number of servers, virtualization is performed. This single shared platform provides homogeneous services to two different retirement homes, located in different counties. It means that no servers are installed in retirement homes.

The Mazadoo platform, based on an Alcatel-Lucent solution, is a SIP powered infrastructure which provides: Voice and video Real time IP Communication, Unified messaging (text or voice messages deposit, notification and consultation), Text-to-Speech, conferencing, openness through standard XML Web Services for application development but also through the standard SIP protocol to support devices such as a Set Top Box. Mazadoo application is developed on top of this XML Web Service API. Users' devices are connected to the platform using SIP protocol. The Mazadoo application collects Facebook contents, aggregates and adapts them.

Participants. The 4 active volunteers plus 2 out of the 3 idle volunteers of our previous AIPA project have accepted to continue with the experiment of Mazadoo. Additionally Mazadoo is deployed in a second retirement home where 6 elderly have been recruited with 26 of their relatives. 6 other elderly persons interested in Mazadoo are to be enrolled. Sociologists and ergonoms are following the experiment and help in adapting Mazadoo to the observed usage. They closely follow the elderly and help them in learning how to use the system.

4 Conclusion

This paper describes a technical platform dedicated to the elderly in retirement homes. The goal is to offer services to preserve, enhance, or create social ties. The

[4] ImaginLab is the very first platform in France to provide both hosted ICT technologies and a panel of users called the *imaginers*. ImaginLab data center provides services, such as Mazadoo, a panel of users through a very high speed internet connection based on FTTH (Fiber to The Home) and FTTB (Fiber To The Building) at 100 Mbps. More info on ImaginLab: `http://vimeo.com/15623507`, `http://imaginlab.fr/blog-en/`.

last evolution of the project Mazadoo has lead to new services belonging to the web 2.0 area. Elderly people are now connected to Facebook. For acceptability reasons, services are accessed via TV, remote control and phone. The elderly can receive messages (text, pictures, and videos) from their contacts, access to local news, check the calendar of the retirement home activities, etc. Moreover, they can now react to content, and post voice mail comments via their phone. This extends their cloud of friends.

The project is conducted by a multidisciplinary team composed of industrial-workers, academics, engineers, ergonoms and sociologists. The prototype is deployed, installed in the individual rooms, and tested by some real users from two selected retirement homes. The professionals showed a strong interest and are opening Facebook pages for their institution to show activities and publications to the remote families, and also add agenda entries to the elderly peoples' news-feeds. The cities involved are also animating Facebook content and communities. We are conducting interviews and usage studies since the end of the project.

Futures are now to add services such as: hobbies (accessing Facebook pages selected through preferences profile), social games, etc.

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Evaluation of Video Reminding Technology for Persons with Dementia

Chris Nugent[1], Sonja O'Neill[1], Mark Donnelly[1], Guido Parente[1], Mark Beattie[1], Sally McClean[1], Bryan Scotney[1], Sarah Mason[2], and David Craig[2]

[1] Computer Science Research Institute, University of Ulster, Northern Ireland
{cd.nugent,s.oneill,mp.donnelly,g.parente,mp.beattie,si.mcclean, bw.scotney}@ulster.ac.uk

[2] Belfast City Hospital/Queen's University of Belfast, Northern Ireland
{david.craig,s.mason}@qub.ac.uk

Abstract. One of the main features associated with those suffering from dementia is memory loss. Recent studies have shown that the deployment of technological reminder based solutions, have to a certain extent, been capable of alleviating some of the issues associated with memory loss. Nevertheless, technical and usability challenges are still major hindering factors to large scale uptake. This work presents the details of the evaluation of a mobile phone based video reminding system with 4 persons suffering from mild dementia. We gathered 101 days worth of usability data during an evaluation period of 5 weeks along with a qualitative collection of pre and post evaluation questionnaires. The results from our evaluation have shown that out of 216 reminders delivered during the evaluation period only 18 of them were not acknowledged by the persons with dementia. Upon examining the post-evaluations, it was found that the carers played a significant role in terms of the success of the solution and that an initial settling in period of on average 14 days was required before users felt comfortable using the technology.

Keywords: Assistive technologies, mild dementia, video based reminders, mobile healthcare.

1 Introduction

Given the ever increasing effects that changing demographics are having on our society it is evident that new approaches to both the management and delivery of health and social care will yield many benefits. This is becoming increasingly important taking into account the increased prevalence of chronic conditions within the older population. Within this cohort, one of the most prevalent types of chronic conditions is that of dementia. Figures recently published by Wimo & Prince [1] have suggested that the numbers of those suffering from dementia will double within the next 20 years and treble within the next 40 years. At present the annual costs required to support those suffering from dementia have been estimated to be in excess of £400 billion.

Those suffering from dementia exhibit symptoms including impairments of memory, thought, perception, speech and reasoning. The symptoms of dementia can be

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ameliorated through a medicated intervention, however, it is a degenerative disorder, with progressive and irreversible effects and at present there is no known cure.

In our current work we have aimed to consider the use of technological solutions to aid with the impairments of memory for those suffering from mild dementia. We have evaluated a video based reminding system and considered the effects that this has on both the person with dementia in addition to their carer. In this paper we present the details of the evaluation and consider the practical challenges in evaluating such a solution.

2 Background

There are clear benefits of improvement in the quality of life for those suffering from dementia along with reducing the levels of burden being placed on both formal and informal carers through the introduction of technology based solutions which have the capability to provide memory support [2]. It must be fully appreciated that technological interventions have not been purported as the definitive solution, however, more as an approach, which if deployed appropriately can have a positive impact on supporting memory needs.

Traditional approaches to memory support have involved the use of post-it notes and diaries. Nevertheless, usage of these rudimentary approaches have suffered due to their inherent requirement for active engagement by users, which, due to the nature of dementia frequently result in them being overlooked. Solutions which rely on a less proactive level of user engagement for reminder delivery have therefore an added advantage. It is within this area that technological based solutions have been able to offer levels of reminding support with varying degrees of success [2].

Cognitive prosthetics have the functionality of supporting people with memory impairment through the provision of timely prompts in relation to scheduled tasks. A crucial requirement is the mobility of the prosthetic, hence the large number of research studies which have focused on the utilisation of pagers, personal digital assistants (PDAs) and mobile phones. Neuropage, one of the first electronic cognitive prosthetics is a text-based reminder delivered through a pager [3]. More recent developments such as Memojog [4] MEMOS [5], ICUE [6], CogKnow [7] and PEAT [8, 9], all use mobile phones or PDAs to deliver their mostly text-based reminders. Utility such as bidirectional communication (MEMOS [5]) or complex scheduling assistance (ICUE [6], Autominder [10] and PEAT [9]) has been investigated to achieve minimal intrusion into the everyday life of the patient with maximal value for the patients and carers involved. Recent developments in this area have involved the assessment of compliance to the prompt as performed by sensors distributed throughout the house (PEAT [8]) or through a mobile robot (Autominder [10]).

The commercial market of assistive technology has established itself around the same utility, with pager-based systems such as Voice Cue (QED), MEM-X (QED), and Timepad (Attainment Company) in addition to text-based prompts delivered through PDAs as provided by AbleLink Technologies (Pocket Compass), Community Integration Suite and Schedule Assistant. In addition to these examples, the Jogger (Independent Concepts), ISAAC (Cogent Systems), Pocket Coach (AbleLink Technologies) and Visual Assistant (AbleLink Technologies) also have the utility to guide the user through the different steps of an activity by means of pictures and text.

Although a wide range of reminding technologies have been developed from both research and commercial perspectives, the extent and depth to which they have been both evaluated and supported during evaluations have to a certain extent provided incomplete sets of evidence to support their further usage on a large scale. Table 1 provides a brief overview of some of the reminding technologies which have been evaluated along with an estimation of how many days of exposure to users were involved during the evaluation periods. It is evident that generation of a more compelling rationale along with supporting tools may result in the wider usage of reminding technologies.

Table 1. Summary from literature presenting the details of studies which have investigated the effects of cognitive prosthetics.

	Year	Name of System	What is it?	Target User	Tested User	Tested Time Period	Total Day Count
Tran [11]	2007	Cook's collage	ingredients and instructions to cook	forgetful people	3 young adults	5 cooking sessions, 2 wk	15
Mihailidis [12]	2008	Coach	Handwashing Support	People with dementia	6 pwd (moderate to severe)	8 wk, 40 trials each	Over 330 days
Liu [14]	2008	Indoor wayfinding	PDA, Indoor wayfinding, directions and prompts	cognitive impairment	cognitive impaired, 2TBI, 2 mental retard., 2 PDD, 1 cerebral palsy, age 26-46	1 time trial	7
Szymkowiak [4]	2004	Memojog	PDA, server, carer interface, text based action prompts	memory impaired user	memory impaired users, 12 user, 2 phases 4 drop outs	12 weeks	96
Davies [7]	2009	Cogknow	Home based cognitive prosthetic embedded in smart environments	People with dementia	mild dementia	3 phases, each N=15, P_1=1d, P_2= 1wk, P_3=4wk	540
Wilson [3]	1997	NeuroPage	Pager with prompts	people with brain injury	ABA, 15 samples with organic memory problems (mostly through head injury)	A phase 2-6wk, B phase 12wk, A phase 3wk	180
Wilson [13]	2003	NeuroPage - now commercial	Pager with prompts	people with brain injury	40, traumatic brain injury (13), stroke (7) and others	27 ongoing: μ=12.7mon, max=24mon, N=13 quit after μ=9 mon	around 13,000

3 Methods

Within this Section, details of the reminding technology deployed to support the evalutations along with the approach used to evaluate the participants is presented.

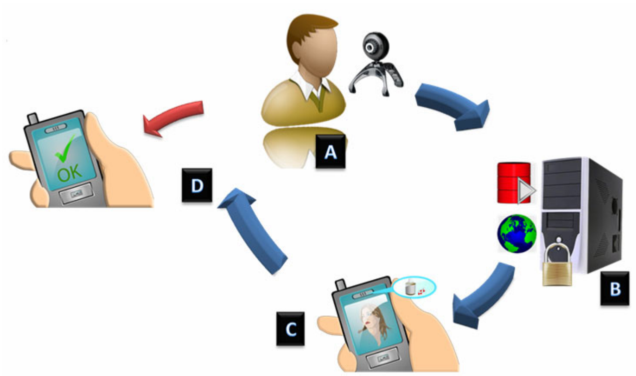

Fig. 1. Overview of the technical architecture of the system including ability to record video reminders, store on a server and subsequently relay all information to a mobile phone [15]

3.1 Technical Components of Reminding Technology

The technology platform used for the reminding evaluation consisted of three main technical components which were used to support both the person with dementia and their carer; a system for the carer with the ability to record and schedule video based reminders, an Apache-based server along with a MySQL database to store all reminders and schedules for all patients and a modified mobile phone used to deliver the video based reminder for the person with dementia [15]. The modified mobile phone can be viewed as the core technical component of the system. It is the responsibility of this component to request new reminders from the server in the form of videos along with the schedule based information of when they should be delivered. The frequency of the requests are pre-programmed within the device and can be personalised depending on the anticipated numbers of reminders to be delivered. Although this component, for the purposes of the Project, was a modified mobile phone, it can be viewed at a general level as a portable device which supports General Packet Radio Service (GPRS) data transmission and multimedia playback in the form of Third Generation Partnership Project (3GPP) and MP4 video. The mobile phone used was a Sony Ericsson W880i.

It is the feature of the video based reminder, which offers the novelty of our approach in comparison to the aforementioned solutions discussed in the previous Section. As depicted in Figure 1, the first stage in the process (A) is for the carer to record a video based message of the reminder to be delivered to the person with dementia. This is completed on a touch screen interface, where following recording the day and time at which the recording should take place is also entered onto the system. The video and the schedule is then relayed to a server (B), which, as previously mentioned, subsequently supports periodic requests from the person with dementia's mobile phone for any updates in the reminding schedule. If, once the server has been contacted by the mobile phone, it detects a new reminder has been uploaded by the carer, the video and the reminding schedule are then downloaded onto the mobile phone (C). At the scheduled time the video reminder is delivered (D) and once acknowledged by the person with dementia an acknowledgement message can be sent back to the server which can be subsequently viewed by the carer. If the reminder is not acknowledged within a certain period of time it will be escalated up to a further 3 times or until the user acknowledges it on the handset.

A number of evaluations have previously been performed on this platform and have been reported in [15, 16]. During these evaluations in excess of 40 elderly participants, persons suffering from mild cognitive impairments and persons suffering from AD have engaged with the system. Nevertheless, the durations of the evaluations have been limited and have in most cases never exceeded 5-7 days. In addition, carers have previously been invited to record a set of reminders in a single session and have not been provided with their own recording station for the duration of the evaluation period.

3.2 User Recruitment

Participants for the study were recruited by clinical research staff during routine attendance at the outpatient Memory Clinic at the Belfast City Hospital. The inclusion criteria involved inviting those patients who were recorded as having mild dementia and who lived alone or with a willing carer able to engage with researchers in the recording of video based reminders on a touch screen computer. Both the patient and carer were involved in the informed consent procedure. It was the intention to enrol participants to the study who had a Mini Mental State Examination (MMSE) of 18 or greater. For the baseline measurements cognition was determined with MMSE and the Disability Assessment for Dementia (DAD) was used to assess functional ability. Pre and post evaluation questionnaires were administered by a research nurse via face-to-face interviews. The aim of the questionnaires were to gain a deeper insight into current levels of both reminding and technology usage, requirements for which types of reminders were required along with the opportunity to provide general feedback about usability of the system and perceived levels of utility. The evaluation period for each participant a maximum of 5 weeks.

4 Results

Four persons with dementia (3 female and 1 male) along with their carers (2 female and 2 male) were recruited for the study (Table 2). The average age of the participants was 70 with the range of carers' ages from 45 years to 77 years.

Within 12 days of starting the evaluation, C12 and their carer withdrew from the study. It was deemed that the solution was too technically complicated to use given the current level of dementia. The user could not understand that the video reminders were to be viewed on the screen of the phone and that it was not necessary to hold the phone to their ear to interact with the reminder. The remaining 3 participants evaluated the system over a 5 week period providing in total a combined number of 101 days of technology usage by people with dementia and their carers. During this period, for the 3 remaining participants, 216 reminders, mostly for medication and appointments, were recorded and delivered to the server, which were then subsequently relayed to the mobile phone. Of these reminders C11 missed 10 out of 146, C14 did not miss any and C15 missed 10 out of 61. Table 3 presents an overview of the missed reminders along with the details indicating if the reminder was acknowledged when initially delivered or if it was acknowledged following escalation on the second, third or fourth time. As can be viewed from Table 3, 74.5% of the reminders were acknowledged on initial receipt. C11 reported that she left the phone at home when she went out, and she would have preferred more flexibility to change reminders. The carer interface, however, was located in her daughter's house as she herself did not have internet access. C15 initially kept forgetting the purpose of the modified phone and was apprehensive to use it. Following approximately two weeks and further encouragement by the carer her level of engagement improved.

Table 2. Details of the 4 participants and their carers detailing baseline measurements of MMSE and DAD

Patient ID	Age	Gender	Length of condition	MMSE	DAD	Carer Age	Carer Gender	Relationship	Living Together
C11	75	Female	2 years	26	78	45	Female	Daughter in law	Together
C12	73	Female	2 years	18	68	77	Male	Spouse	Together
C14	61	Male	4 years	27	60	58	Female	Spouse	Together
C15	71	Female	2 years	25	63	73	Male	Spouse	Together

In addition to the quantitative measures recorded, responses to the post-evaluation questionnaires indicated that all three remaining participants indicated that they enjoyed using the system. In addition, it was reported that they thought the system helped them to remember to undertake the tasks they were meant to do. Only one of the carers thought that it actually saved them time, however, two of the three dyads indicated that they would have liked to keep using the system beyond the trial period. The dyad that indicated otherwise had mixed views. The participant (C11) thought it was not flexible enough for her needs as she was still very active, however, her carer thought that '*she looked and sounded a lot better since the start of the trial*' and thought the reason for this was in relation to improved medication compliance.

Table 3. Details of participants' duration of participation along with metrics relating to the acknowledgements to delivered reminders

Participant	Duration	No. of reminders recorded and delivered	No. of reminders missed	No. of reminders ack. 1st attempt	No. of reminders ack. 2nd attempt	No. of reminders ack. 3rd attempt	No. of reminders ack. 4th attempt
C11	34 days	145	8	108	17	7	5
C12	12 days	/	/	/	/	/	/
C14	27 days	22	0	19	2	1	0
C15	28 days	49	10	34	2	0	3

When asking the carers whether the system would enable their mother/father/partner to stay independent at home, all three agreed. When asked about their willingness to pay, all three indicated that they would happily contribute in the region of £10 per month along with an initial £50 installation fee. One carer commented '*I would pay whatever it costs to help increase the independence*' and that it would be '*invaluable*' if his wife was living on her own.

5 Conclusion

In this study we have presented the details of a novel video reminding based system used to support those suffering from mild dementia. The system was deployed in the homes of 4 persons with dementia and a recording system was given to the carers to allow them to record and schedule the video based reminders. Overall, the system was used by persons with mild dementia and their carers for 101 days during the evaluation period. This is the first time the technology solution has been evaluated to this extent on a user group with 3 from the 4 persons with dementia using the system for between 27-34 days. Following analysis of the data collected during the evaluation period a deeper insight into the usage of video based reminding technology was gained. In the first instance, following analysis of post evaluation questionnaires, it has been our finding that carers play a large role in the success of the impact of the solution.

Secondly, it was also discovered that there is an initial training period required which should be deemed as a settling in period and may affect whether or not the person with dementia and their carer will continue to use the device. The example of C15 and her carer are a prime example for this effect. Had the carer not persisted to offer encouragement in this initial period, withdrawal would have been imminent. C14 similarly reported that it '*took one to two weeks to get the hang of it*'. Our results demonstrated an unexpectedly high reminder acknowledgment rate. This provides evidence to investigate the utility of the service on a larger scale along with extending the period of time within which the evaluations will take place.

Our plans for future work involve the extension of this protocol to support a longer evaluation period in addition to increasing the simultaneous numbers of users which would be engaging with the evaluation. At present we can asses if a reminder has been acknowledged, however, we cannot assess if the task has been completed. We therefore wish to extend our technical platform to incorporate a sensor based framework to assist with compliance assessment of delivered reminders.

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The "Acceptance" of Ambient Assisted Living: Developing an Alternate Methodology to This Limited Research Lens

Robert Beringer[1], Andrew Sixsmith[1], Michael Campo[1], Julie Brown[2], and Rose McCloskey[3]

[1] Department of Gerontology, Simon Fraser University
#2800 – 515 West Hastings Street, Vancouver, British Columbia V6B 5K3
{rmsavage beringer,michael_campo,ajs16}@sfu.ca
http://www.sfu.ca/grc/
[2] Graduate Center for Gerontology, University of Kentucky, 306 Wethington Health Science Bldg., 900 South Limestone, Lexington, KY, USA, 40536
julie.a.brown@uky.edu
[3] Department of Nursing & Health Sciences, Univeristy of New Brunswick, Saint John, PO Box 505O Saint John Saint John New Brunswick, E2L-4L5
Rose.McCloskey@unbsj.ca

Abstract. Ambient Assisted Living (AAL) systems integrate stand-alone assistive technologies with smart homes and telehealth. This paper reports on a study that focused on the envisioned impact of AAL systems on the lives of end-users using an alternate research approach. A qualitative design was used and semi-structured interviews were conducted with 12 older adults in Southwestern British Columbia, Canada. While a high degree of acceptance regarding AAL was found in the present study, the research also discovered that such technologies have the potential to profoundly affect, both positively and negatively, participants meaning and experience of the home environment. These findings suggest that research and development paradigms need to be expanded if our intention is to produce a product that will be accepted and helpful to the end-user.

Keywords: Gerontechnology, ambient assisted living, smart homes.

1 Introduction

A goal of many older people is to be able to remain independent at home and to age-in-place [1]. Information and communication technologies (ICTs) offer considerable potential to help older people realize this goal. One such technology under development is an Ambient Assisted Living (AAL) monitoring system that provides individualized support services and health care within the home. If successful, these AAL monitoring systems can play a key role in helping people adapt to their home environment and to remain in their homes as they age.

AAL in-home monitoring systems are currently under development by consortiums in Europe and the United States [2,3]. The focus of research to date has been predominantly on the development and adaptation of the technology to allow it to operate

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within the home setting [4-12]. The overall conclusion of this research is that there would be a high degree of *acceptance* of AAL among older adults. Although it is found that an AAL system would likely make people feel safer and more secure in their homes, older adults' perspectives on this technology and how it will impact their daily lives has been largely ignored. This perspective is of utmost importance given the willingness of older adults to embrace this technology and is necessary if it is to be truly successful. The purpose of this study was to consult with potential AAL users and to explore their views and concerns on using this technology in the home.

2 Methodology

Due to the exploratory nature of the study, a qualitative approach was employed [13]. A combination of convenience and snowball sampling was used to recruit research participants. Convenience sampling refers to using a sample to which the researcher has access, in this case, neighbourhood networks and the Council of Senior Citizens' Organizations of British Columbia. Additional participants were recruited using snowball sampling where participants who had completed the study provided suggestions on other participants. Alternative sampling techniques may have been employed, but the fact remains that it is difficult to convince older adults to participate in research studies and a selection bias towards overly healthy samples is common [14]. In the present study, the use of convenience and snowball sampling resulted in access to participants who were more likely to be users of AAL in the future.

Data was collected using semi-structured interviews and feedback on a short film on an AAL system. The purpose of the interviews was to elicit data on what home meant to participants and to obtain feedback on an AAL in-home monitoring system. At the beginning of each interview, participants were asked to talk about what home meant to them in terms of the physical, social and personal space. Understanding the meaning of home within the context of the older adult is vital because "as peoples' circumstances change, the ways in which they conceptualize home change(s) as well"(p.318)[15]. Interview's ranged in length from 45 to 75 minutes. After the initial section of the interview where participants described what home meant to them, they were shown a short film titled *Imagine the Future of Aging*, which described a home-based AAL system and the impact of this system on family and caregivers. The film included footage of a medication reminding device, in-home monitoring of activities via sensors, vital signs monitoring, video conferencing, and cognitive function monitoring by way of an assessment tool embedded in an electronic card game. Upon completion of the film, participants were asked to describe their thoughts and feelings about the film's content and the potential effect that AAL may have on the meaning of their own home environment. This open-ended approach was used to encourage participants to freely share their feelings and to avoid imposing the researchers' own beliefs and understandings onto participants. This approach to data collection is widely accepted and valued for its ability to develop a better understanding of participants' perspectives [16].

Prior to each interview, participants were asked to complete a brief demographic profile which included questions on sex, age, chronic health conditions, use of assistive devices, self-rated health status, history of falls in the home, frequency of pain, and hospitalizations in the year prior. These questions were asked to ensure that the participants in the study were in fact individuals who may benefit from some form of assistive technologies.

Interviews were transcribed verbatim and analyzed using NVivo 8, a software package designed to manage and analyze qualitative research data [17]. Each interview was read multiple times to identify commonalities and uniqueness within and across interviews. Themes were identified that represented the salient behaviors and prevailing perspectives of participants. Analysis was iterative as data was gathered and analyzed concurrently over the course of the study. This process continued until a point of theoretical saturation was reached where new interviews were found to add very little to the themes that had emerged. Descriptive statistics were obtained on data from the demographic profiles.

3 Results

Of the 12 people who participated in this study, 9 were female, and 3 were male (M= 75.6 yrs; age range 61-95 yrs), with a mean of 3.75 chronic conditions and 41.6% of participants (5 of 12) relying on an assistive device to function within the home. Only 25% of participants (n=3) rated their health as excellent, 25% (n=3) rated their health as very good, 16.7% (n=2) rated their health as good, and 33.3% (n=4) rated their health as fair. None of the participants rated their health as poor. Less than half of the participants (4 or 33.3%) experienced a fall in the home. One of these falls was serious enough to result in broken bones, and two participants reported falling in the evening and having to remain on the floor overnight until help arrived. The majority of participants (9 or 75%) admitted to experiencing pain on a regular basis with 33.5% (n=4) reporting very mild pain, 8% (n=1) reporting mild pain, 16.7% (n=2) reporting moderate pain, and 16.7% (n=2) reporting severe pain. None of the participants reported very severe pain. Half (n=6 or 50%) reported being hospitalized in the year prior to this study. Of those who were hospitalized, 5 or 83.3% had been hospitalized twice; the mean length of stay for these hospitalizations was 11 days (range 1-60 days).

The four themes that emerged from the interview data were independence, security, privacy, and interference with current lifestyle. Overall, participants spoke of how an AAL system could enhance their independence by allowing them to remain in their homes longer. There was general agreement amongst participants that having an AAL system would enhance their security by knowing that somebody would be alerted if they experienced any difficulties such as a fall or a sudden change in health status. Conversely, each participant spoke at some length about the impact an AAL system would have their privacy. Participants believed that their privacy may be compromised and they stressed the importance of obtaining consent from the individual targeted prior to installing the AAL.

The final theme, which was a major focus of many of the interviews, was how an AAL system would interfere with current lifestyles. Specifically, they expressed great concern about the potential of an AAL system to affect their behavioural freedom within the home space. In fact, several reported they would likely conduct their lives differently under the perceived watchful eye of an AAL. For example, when commenting on whether AAL could change the way he felt about his home, Alex responded:

> "Possibly yes, oh yeah I am positive that it would because I would have to dress up for all occasions (referring to videoconferencing), I couldn't just walk dishevelled and unshaven and what not, because I would be watched, so it changes your behaviour a lot... I couldn't be messy, it couldn't be messy if people could see it so it would make me work much harder, it would put some responsibility on things being in place and nothing that could disturb the picture, but that's just me, maybe there are plenty of people that could take it."

As noted above, participants were uncomfortable with the notion that people would be able to see how they looked and how the videoconferencing component of the AAL system would force them to attend to their grooming, personal appearance, and housekeeping tasks more than usual. This sentiment was reinforced by Olivia who spoke about the effect ongoing surveillance would have on her day-to-day well being:

> "I'd worry about the darn thing… it would only increase my blood pressure."

These feelings were echoed and expanded on by Bob, who in commenting on the AAL system as a whole stated the following:

> "I think if you had to be monitored at that level you'd really begin to wonder is it worth it all? I think it would, depending on the individual, I think it would really destroy a person's self worth…I'm no longer capable of going to the bathroom without being checked… I'd begin to wonder maybe I don't belong here, I'm incapable, I think it would be really devastating to some peoples self worth to be that monitored."

Bob's comment points to the intrusiveness he felt when envisioning what life would be like with sensor technologies in the home. Bob's remark suggests that having these technologies in his home would serve as a reminder of the deficits people experience in their lives and may raise doubt about their existing capabilities.

One participant spoke of how an AAL system would interfere with her current lifestyle in a positive manner.

> "I find that when I'm looked at a lot by doctors (referring to the vital signs monitoring in the film), I feel more comfortable and not worrying that there might be something wrong."

This shows that ongoing surveillance would be welcomed by some, but for others could pose some challenges and may not be readily accepted.

4 Discussion and Recommendations for Future Research

The findings from the themes of independence, security, and privacy coincide with much of the previous research in this area. Like in previous research, participants in this study recognized and valued the impact AAL could have on their day-to-day life in terms of remaining safe in their homes and being able to age-in- place. This finding is significant as it reinforces the work that has been done in this area to date.

It also demonstrates that the views of researchers and developers in terms of how AAL systems can affect independence, security, and privacy are consistent with that of potential end-users. This is important because it highlights the importance of continued work in this area.

One area that emerged from this study that has not been previously identified was the nature and scope of effect an AAL system would have on users ability to freely conduct themselves in their home. Much of the previous research into AAL and assistive technologies evaluated older adults’ perceptions of AAL with the use of yes/no type questionnaires and questions with Likert scales. In asking the participants in the present study to envision what it would be like to live with AAL in their homes, participants were able to describe, not only whether or not they would accept AAL, but also the potential for such a system to affect what *home* potentially means to the user. Participants envisioned a number of scenarios: that the person and home would need to be neat in order to videoconference; that vital signs monitoring could cause stress; and that excessive monitoring could remind them of the deficits they are experiencing in their lives. This rich data has previously been unavailable and represents the beginning of a process, linking the technology development field to a critical gerontological perspective. The research suggests such links must be considered when planning to implement and evaluate AAL systems.

The present research highlights the lack of progress made in how society currently views aging and the development of technology (in this case AAL). Almost 5 decades ago, Jacques Ellul [18] made the following statement when discussing the evolution of technology:

> “The further we advance into the technological society, the more convinced we become that, in any sphere whatever, there are nothing but technical problems. We conceive all problems in their technical aspect, and think that solutions to them can only appear by means of further perfecting techniques” (p.414).

The manner in which we currently view aging as *problems* [12] that require technological solutions such as AAL suggest we have made little progress in our approach since Ellul’s words almost fifty years ago. To confound matters Ballinger and Payne [19] have noted that these problems are transformed into risk by way of a completely rational perspective. Simply, a risk is identified as a predictable event that health professionals, system developers, and researchers have a duty to try and prevent. In many ways AAL represents a set of technological solutions developed to deal with a cluster of risks. Consider some of the components of AAL contained in the film *Imagine the Future of Aging*: the risk of falls is solved via sensor technology; the risk of medication compliance is solved via a dispenser and watch; the risk of safety is solved via smart technologies; and the risk of social isolation is solved via videoconferencing. The commentary from participants in the present study suggests that these risks have been identified by experts rather than in consultation with older adults. This raises the question that the apparent assumption of AAL, that older adults want to be protected from every imaginable risk, may in fact be misguided.

These findings suggest that future research should be directed towards not only asking potential users if they would accept the system, but rather probe how it would feel for the user to interface with the technologies on a daily basis. The findings of this study suggest that AAL could in fact act as a stimulus to cause individuals to behave and feel differently in their own homes, in essence, potentially altering what home means to these end-users. In terms of the original research questions that guided this research, new findings were somewhat limited, however, the behavioural and home meaning findings are very unique. The true value in the present study was in exploring this new lens to gather feedback from potential AAL users. The results of this study display that the lens of home meaning must be viewed as a major contributor in uncovering the unique concerns reported herein among potential AAL users. These findings suggest that research and development paradigms need to be expanded if our intention is to produce a product that is truly friendly to the end-user.

5 Limitations

The study was small and the sample size did not allow for any quantitative statistical analysis beyond descriptive statistics. The qualitative approach nevertheless resulted in rich data that identified numerous concerns for potential AAL users in the context of the meaning of home. Finally, while the sample included both participants that owned and rented their current homes, the sample was not specifically screened for socioeconomic status. The present sample therefore is likely higher than average in terms of education and socioeconomic status.

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An OWL-DL Ontology for the HL7 Reference Information Model

Ashraf Mohammed Iqbal

Faculty of Computer Science, Dalhousie University,
6050 University Avenue, Halifax NS B3H 1W5, Canada
iqbal@cs.dal.ca

Abstract. Representing knowledge via building an ontology for healthcare messages is important to achieve semantic interoperability among healthcare information systems and to better execute decision-support systems. HL7, an ANSI-accredited developing organization, developed the most widely-used messaging standard in healthcare information systems. This messaging standard, in its version 3, is based on an object-oriented model called the Reference Information Model (RIM). In this paper, a description logic-based ontology in Web Ontology Language for HL7-RIM is proposed. This proposed ontology is used to instantiate medical records written in HL7, and also has been used to reason a sample medical rule. The evaluation results show that the ontology can capture necessary clinical information elements and can be used successfully by decision-support systems.

Keywords: HL7, RIM, OWL, Ontology.

1 Introduction

Health Level Seven (HL7), an ANSI-accredited standards developing organization, developed the most widely-used messaging standard in the healthcare domain. In version 3 of HL7, the messaging standard is based on its object-oriented Reference Information Model (RIM). In order to achieve full semantic interoperability among different healthcare information systems, knowledge representation of HL7 messages (i.e., of HL7-RIM in version 3) is crucial. Representational knowledge of RIM can be used by medical decision-support systems to produce more effective results, while ontology as a knowledge representation method has proven useful in various areas of health informatics. Since most of the clinical settings are currently using HL7 messaging standard for communication, we argue that a coherent ontological representation of such messages ease implementing decision support systems with minimal changes of the current settings.

There have been some ongoing efforts in the ontological engineering of HL7-RIM, but most of these ontological representations are either incomplete, built on earlier versions of RIM, or are based on a considerably weaker methodology (e.g., frame-based ontology). Hence, we argue that a comprehensive ontology is necessary for the latest version of HL7- RIM. This ontology should be sufficiently flexible to adapt to changes made in design specifications of RIM.

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In this paper, an OWL-DL ontology of the latest version of HL7-RIM is proposed. The attributes of HL7-RIM are defined to use the data types specified by HL7 itself, and are also bound to take values from the HL7 vocabulary domains. The HL7-RIM classes, HL7 data types and HL7 vocabularies are modeled as the top-level classes in the ontology built using Protégé 3.4 beta. OWL-DL has been used for building the ontology where automated reasoning is possible, and RACER [12] has been used for reasoning purposes.

Our proposed HL7-RIM ontology is evaluated against standard ontology design principles [9, 10]. Two sample medical records represented in HL7 [11, 16] are instantiated using the proposed ontology. Also, a sample example has been shown to show how we can reason the proposed ontology. The evaluation results show that the proposed ontology has the capability to capture clinical records in HL7 and can be used by decision-support systems for reasoning purposes.

The rest of this paper is organized as follows: Section 2 reviews some related works. Section 3 briefly describes the proposed OWL-DL ontology for HL7-RIM. Section 4 presents the results, and Section 5 summarizes the findings and concludes the paper.

2 Related Works

Samson Tu from Stanford University [1] built an ontology of HL7-RIM data types and top-level classes (i.e., Act, ActRelationship, Entity, Participation, Role, RoleLink). This was a frame-based ontology developed in Protégé 2000.

Orgun and Vu [2] developed a full ontology of HL7 for the version 1.15 of RIM based on Tu's design principles. They adopted all of Tu's modeling decisions in their frame-based ontology. The high-level classes of the minimal top-level ontology were for HL7 data types, HL7-RIM classes, and HL7 vocabulary domains with sub-classes. The attributes of each class were modeled as slots with data type, cardinality, inverse values, and template values. The vocabulary classes were grouped in the hierarchy according to definitions in the vocabulary domain of HL7. Each frame was given a unique identification by creating a slot meta-class and a slot called ID of this class for mapping with HL7 message structures. The top-level classes had corresponding slots for ID. Orgun and Vu [2] instantiated their system with a small sub-set of HL7 messages for Patient Admission and Patient Demographic Query Events. However, the instantiations for complete medical records were left for future work.

Helen Chen of W3C [3] developed another complete ontology for HL7-RIM for the version Ballot May 2006. The basic difference between this ontology and the previous two is that Chen built a rule-based ontology instead of a frame-based one. The top-level classes were modeled for HL7 data types, HL7-RIM classes and HL7 vocabulary domains. The associations among classes were modeled as object properties with domain, range classes, type of properties (e.g., symmetric, inverse, etc.). The data types of each class were also modeled as object properties, with the range class set to the corresponding data-type class. The relationship classes of HL7-RIM (e.g., ActRelationship class, RoleLink class) were modeled as properties instead of classes, with their types as sub-properties.

Both the ontologies developed by Samson Tu [1] and Orgun and Vu [2] were built as frame-based ontologies. We argue that a rule-based ontology can improve knowledge representation for a number of reasons as described in [8]. Helen Chen's ontology [3] also has some limitations such as no asserted conditions were applied, no sufficient or necessary conditions were applied, the disjointedness among classes was not applied etc.

All of the ontologies were built on older versions of HL7-RIM. The newest version was adopted by Helen Chen (ballot of 2006). There have been 14 releases of RIM since January 2006 with changes not only in classes or data types but also in design principles. For example, the HL7 released the normative edition of RIM in 2007. This is why a new ontology is necessary to reflect the changes initiated by HL7 for improving message communication structures.

Moreover, none of the ontologies was instantiated with real world medical data. Although Borgun and Vu [2] instantiated their ontology with some small sub-sets of HL7 messages, the data could cover only a very small area of medical data (mostly the demographics of a patient).

3 Proposed OWL-DL Ontology for HL7-RIM

The proposed Description Logic based ontology for HL7-RIM is built in Web Ontology Language (OWL). Protégé 3.4 beta was used to model the ontology. Detailed modeling decisions are discussed in the following sections.

3.1 Modeling Decisions for RIM Classes and Attributes

The classes of HL7-RIM version 2.26 [7] were modeled in Protégé ontology as top-level classes. Three foundation classes (i.e., Acts, Entities, Roles) of the HL7-RIM base model along with the subject area class Infrastructure Communication were modeled as top-level classes in the Protégé ontology. Those top-level subject areas were modeled as sub-classes of top-level classes while making further sub-classes for their specializations. The subject areas MessageControl (classes used for representing control, communication and acknowledgement of messages) and QueryControl (classes used to formulate, communicate and respond to query messages) were modeled as sub-classes of InfrastructureCommunication class.

The back-bone class RoleLink, which defines dependency and relationships between two roles, was modeled as a sub-class of class Roles while building object properties to ensure associations between Role and RoleLink classes. Similarly, another back-bone class ActRelationship was modeled as a sub-class of the class Acts. The association between Act and Role (i.e., the context of an act while playing a role) was designed in RIM as a back-bone class called Participation. We made this class as a sub-class of Acts in our ontology while ensuring many-to-one relationships from it to both Act and Role classes by using object properties. There was lack of reflexive closure of generalization relationships for classes in RIM. The current ballot [7] made sub-classes of Act, Role and Entity, which in turn represent their generalizations (e.g., Act is an Act). We modeled these concepts as sub-classes of their corresponding classes while making both classes equivalent. For example, the ActHeir class was a sub-class of the Act class and was equivalent to Act. Since in RIM these special classes were designed as sub-classes of CoreInfrastructure class, we ensured the multiple inheritances in our ontology.

The classes were made a disjoint of each other where applicable. For example, the classes Acts, Roles and Entities were made disjointed to each other, but InfrastructureCommunication was not made disjointed to any of these, since it contains the equivalent classes to Act, Entity and Role.

3.2 Modeling Decisions for RIM Associations

Different types of associations are modeled in different ways. These are discussed below.

One-to-Many Associations. One-to-many associations are very common in object-oriented paradigms. As HL7-RIM is an object-oriented model, there are a few examples of one-to-many associations among its classes.

We adopted the procedure proposed by [13] for modeling such one-to-many associations. An object property was created by setting the domain as the source class and the range as the target class. As we know that the functional property can have only a single value for an instance of a class, the property was made functional. The inverse of this property was also created, which was inverse functional.

(0..1)-to-Many Associations. These associations were modeled in Protégé ontology by creating an object property with the domain as the source class, the range as the target class, and by setting the maximum cardinality of the property equal to one. The inverse of this property was also created.

(0..1)-to-One Associations. These associations were modeled similarly to (0..1)-to-many associations, except here we made the object property inverse functional, i.e., the inverse property should be functional and can take a single value for each instance of the target class.

(1..*)-to-Many Associations. Here, we set the minimum cardinality of the object property (from source to target class) equals to one. We also created inverse property for this property.

3.3 Modeling Decisions for RIM Data Types

HL7 has its own data-type standard. The normative Ballot version 3 of their data type was defined in May of 2009 [14]. The data types were modeled as Protégé classes in our ontology. However, we assume that the implementation of these data types will be done in the execution step. There are specializations of data types defined in its abstract specification [14] which were modeled as sub-classes of their generalization data types. For example, the data type QTY (i.e., Quantity) has specializations RTO (i.e., Ratio), QTZ (i.e, ZeroedQuantity) and TS (i.e., TimeStamp). Each data type contains a number of attributes which were modeled as object properties with domain as the data-type class and range as the data-type class of that attribute. The attributes of HL7-RIM classes were modeled as object properties, with the domain as the RIM class and the range as the data-type class. There are restrictions on the attributes of HL7-RIM classes. For example, there should be exactly one class code for each instance of Act class. These restrictions were modeled by setting the cardinalities (minimum, maximum, exactly) for the attributes in the RIM classes. There are some usages of the same data types with different parameters in RIM. For example, the data type of the attribute unitPriceAmt is RTO< MO, PQ> for the class InvoiceElement, whereas it is RTO<PQ, PQ> for the attribute unitQuantity of the same class. This was modeled by creating sub-classes RTO_MO_PQ and RTO_PQ_PQ under the data-type class RTO. Similarly, sub-classes were built for classes SET, BAG, IVL, etc. The class COMP is defined in HL7 data types for comparing two values whose returns are either true (if the two values are equal) or false. Thus, this data type was modeled as a sub-class of the data-type BL (i.e., boolean).

3.4 Modeling Decisions for RIM Vocabularies

HL7 defined the specification of the latest version of its vocabulary in March 2009 [15], where internally-defined vocabulary sets as well as some external vocabulary sets (e.g., SNOMED, LIONC, etc.) were incorporated. We modeled only the internal vocabulary domains in our ontology as these are used for binding the domains of HL7 attributes.

The top-level vocabulary domains were modeled as classes in our Protégé ontology and the specializations as the sub-classes of their generalized domains.The value sets of each vocabulary domains were modeled as ValuePartitions with CoveringAxioms. The concept domains for attributes of RIM classes were modeled as specifying the ‘AllValuesFrom’ restrictions on the attributes.

4 Results

We evaluated our proposed HL7-RIM ontology against standard ontology design principles proposed in the literature [9, 10]. We also instantiated two sample medical records written in HL7 [11, 16] using the proposed ontology. Moreover, we also demonstrated how we can reason the proposed ontology using an example for the rule described in [17].

4.1 Evaluation for Compliance with Standard Design Principles of Ontology

We manually checked the compliance of our proposed HL7-RIM ontology against two sets of standard design principles: Gomez-Perez's ontology design principles [9] and Bodenreider's design principles [10]. While the design principles proposed by Gomez-Perez [9] are a bit more theory-oriented and abstract, the ones proposed by Bodenreider [10] are more development-oriented. We found that our proposed ontology satisfies the basic principles of Gomez-Perez [9]. Among the design principles proposed by Bodenreider [10], some were already enforced by Protégé. We examined the rest and found that the criteria ‘Non-leaf classes must have at least two children’ was partially satisfied by our ontology, with some exceptions (e.g., the Procedure class has only one child, SubstanceAdministration). This is understandable, since the main target of our work is not to change the design specifications of RIM itself but to build an ontology by following the specifications.

4.2 Checking Logical Consistencies Using Reasoners

We checked the logical consistencies and proper classification of taxonomies in the proposed EMR ontology automatically using two reasoners – Pelett 2.2.2 [18] and RacerPro 2.0 [12]. Pellet is an OWL-DL reasoner with a plugin for it in Protégé. RacerPro is another description logic ontology reasoner used to identify possible logical inconsistencies and improper classification of taxonomy. Both of these two reasoners found no logical inconsistencies (e.g., loops) in our HL7-RIM ontology.

4.3 Instantiations of the Proposed HL7-RIM Ontology

We instantiated the proposed ontology with two medical records [11, 16] written in HL7. This first record covers the basic medical components used in practice (e.g., demographics, physical exams, diagnostic tests, medications, therapies, procedures etc.) where the second record aimed to incorporate the components pertinent for continuity of care delivery. Both of these records were successfully instantiated by our ontology. This can be easily understood since both are already written in accordance with the HL7 CDA specifications. However, we could not show the details of the instantiation results here due to space limitations.

4.4 Reasoning of the Proposed HL7-RIM Ontology

One of the major achievements of the proposed HL7-RIM ontology is that it can be used for reasoning purposes by decision support systems for particular diseases. We believe that our proposed ontology provides all the necessary information elements that would be needed for that purpose. Here, we would like to demonstrate an example of how it could be used for reasoning purposes by using an example of a simple guideline rule showed by Rector et.al. [17]. We can not show here the rule for the space limitation. However, we are going to show how this rule can be reasoned using our proposed ontology using description logic here:

$$
\begin{aligned}
&?x : Person \wedge ?y : Patient \wedge hasParticipation(?x, ?z) \wedge ?z : Participation(typeCode = \text{'}SUBJ\text{'}) \wedge \\
&hasParticipation(?z, ?a) \wedge ?a : Observation(classCode = \text{"}COND\text{"}, codeSystemName = \\
&\text{"}SNOMED-CT\text{"}, code = \text{"28119000"}) \wedge (hasParticipationAct(?z, ?c) \wedge ?c : Observation \\
&(codeSystemName = \text{"}SNOMED-CT\text{"}, code = \text{"439953004"})) \wedge (hasParticipationAct(?z, ?d) \wedge \\
&?d : Observation(codeSystemName = \text{"}LOINC\text{"}, code = \text{"10157-2"}, value = (codeSystemName \\
&= \text{"}SNOMED-CT\text{"}, code = \text{"56265001"}))) \wedge \neg(hasParticipationAct(?z, ?e) \wedge ?e : Observation \\
&(codeSystemName = \text{"}SNOMED-CT\text{"}, code = \text{"127013003"})) \wedge \neg(hasParticipationAct(?z, ?f) \wedge \\
&?f : SubstanceAdministration(codeSystemName = \text{"}LOINC\text{"}, code = \text{"22312-3"})) \\
&\rightarrow hasParticipation(?z, ?g) \wedge ?g : SubstanceAdministration(codeSystemName = \text{"}LOINC\text{"}, \\
&code = \text{"22312-3"})
\end{aligned}
$$

5 Conclusion

We have proposed a comprehensive OWL-DL ontology for the latest version of HL7-RIM. We believe that such an effort of knowledge representation of clinical messages would be a step forward towards achieving full semantic interoperability among healthcare information systems and can further be used by decision-support systems for reasoning purposes. The evaluation results show that our proposed ontology can capture the elements of clinical records and has the capability of representing the information on a patient's medical records. Moreover, we believe that the proposed ontology is sufficiently flexible to reflect any changes made in the design specifications of RIM.

Nonetheless, there are a few shortcomings of HL7-RIM from an ontological point of view [4-6], such as: RIM cannot differentiate between continuant and occurant, RIM cannot differentiate between primary and secondary acts, etc. The research reported in this paper aims to engineer an ontology for RIM. However, our future work would include investigating whether these limitations can be overcome by using reasoning rules. An automated way of parsing clinical XML messages in HL7 and instantiating the proposed ontology would also be interesting to implement.

The research reported in this paper is part of a larger project to create clinical decision support systems instantiated by HL7 messages. Our HL7-RIM ontology will not only support this project but can also be used as a switching language among various EMR standards.

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Development of the "Care Delivery Frame" for Senior Users

Yi-Shin Chen, Yeh-Liang Hsu, Chia-Che Wu, Yen-Wei Chen, Ju-An Wang

[1] Mechanical Engineering Deptartment, Yuan Ze University, Chung-Li, 32003, Taiwan
[2] Gerontechnology Research Center of Yuan Ze University, Chung-Li, 32003, Taiwan
s988704@mail.yzu.edu.tw, mehsu@saturn.yzu.edu.tw

Abstract. The "Care Delivery Frame (CDF)" presented here integrates two distinctly different applications, the home telehealth system and the remote photo sharing service of digital photo frame, to create a unique information channel for senior users who are not familiar with the operation of computers and Internet. In addition to health data monitoring, children or caregivers can "deliver care" to their seniors not living together by warm messages and thoughtful reminders on the CDF, as well as sharing their feelings, joy, and life experience through photos and video clips. CDF is positioned as the software for providing care and positive emotion to senior users, with the emerging new class of computers – the "Pad PC", as its major target platform. CDF is the smallest possible home telehealth system that can be established between a single user and his/her care giver. It is our answer to the current difficulties and challenges of home telehealth systems.

Keywords: Gerontechnology, Home Telehealth System**,** digital photo frame.

1 Introduction

Most developed countries are facing the problem of increasing number of elderly population. The need of health care and management for the elderly is an urgent issue. Home has become the centerpiece of health delivery system today. Intensive monitoring of health parameters in the home environment is necessary for health care and management. Telehomecare, or the more modern term home telehealth, can be defined as "the use of information and communication technologies to enable effective delivery and management of health services at a patient's residence" [1]. Home telehealth allows patients the dignity of remaining in their own home for as long as possible by providing care that is equal to or superior than approaches that rely solely on health providers coming into the home for scheduled visits [2]. Most home telehealth systems adopt the following sequence for health data monitoring: measurement of various health data, health data transmission, data storage and analysis. Finally medical actions will be taken if necessary. The technical emphasis is on establishing an information channel for health data transmission between homes and hospitals or other home healthcare service providers. The "care" in such systems often refers to professional health care [3]. Although the usefulness of the home telehealth system

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has been recognized in many studies, and all technologies required are readily available, expectations for its widespread adoption have not been realized. Coughlin also pointed out that, there is a growing awareness of the need for new ways to improve the well-being of older people at home as well as the availability of increasingly affordable technology and computational power, consumer and clinician adoption has been slow [4].

Aging is associated with an increasing risk of isolation [5]. In U.S, there were 27.39% of the 65 years old and over population who lived alone [6]. In addition to transmitting health monitoring data, the essence of "care" to the senior should emphasize more on the care from people in the forms of warm messages, thoughtful reminders, and sharing feelings, joy, and life experience. We need to establish an information channel so that the love ones, children, family members, and care givers can easily "deliver care" to the seniors not living together.

To those users who are familiar with computers and Internet, the PC is the most important and irreplaceable information channel. Information access, interpersonal communication, audio-visual entertainment, shopping, distance learning, and health care, can all be achieved on a PC connected to the Internet. However, there is still no proper information channel for those people who are not familiar with computers and Internet, such as the seniors.

The "Care Delivery Frame (CDF)" presented in this paper integrates two distinctly different applications, the home telehealth system and the remote photo sharing service of digital photo frame, to create a unique information channel for senior users who are not familiar with the operation of computers and Internet. In addition to health data monitoring, children/caregivers can "deliver care" to their seniors not living together by warm messages and thoughtful reminders on the CDF, as well as sharing their feelings, joy, and life experience by displaying photos and video clips remotely on the CDF. Even more applications can be imagined once this information channel to the seniors at home is established, such as entertainment, displaying life information or even commercial ads.

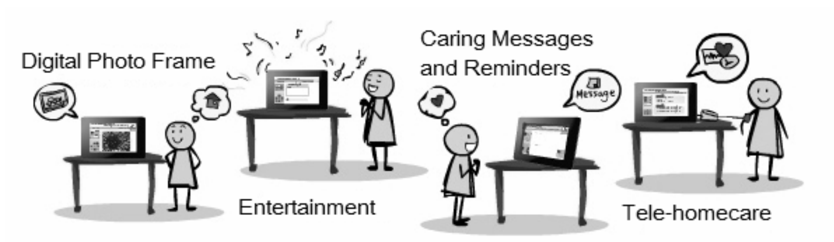

Fig. 1. The 4 main functions of the Care Delivery Frame

As shown in Figure 1, CDF provides the following 4 main functions:

(1) Home telehealth: The basic function of CDF is the home telehealth system. All technical functions of a home telehealth system are built in the CDF. Currently the vital sign sensors that can be connected to CDF are blood pressure meter, blood glucose meter, and weight scale.

(2) Remote photo sharing: CDF provides a platform for children and caregivers to upload photos and videos clips remotely, and manage the display sequence and timing on the CDF for their seniors not living together.
(3) Caring messages and reminders: Children/caregivers can send warm caring messages and thoughtful reminders to their seniors to display on the CDF.
(4) Entertainment and life information: Collaborating with information service companies, CDF can also be a platform to display life information such as weather, shopping, as well as music and other entertainment information.

2 Information Structure for CDF

Figure 2 shows the information structure of the "decentralized home telehealth system" proposed by Gerontechnology Research Center (GRC), Yuan Ze University [7]. In this structure, a single household is the fundamental unit for sensing, data transmission, storage and analysis. The core of the system is the "Distributed Data Server (DDS)" inside a household, which can be a hardware thin server or software running on a PC. Health monitoring data is stored in the DDS within the household, instead of transmitting the health monitoring data to a centralized database in a home healthcare service provider.

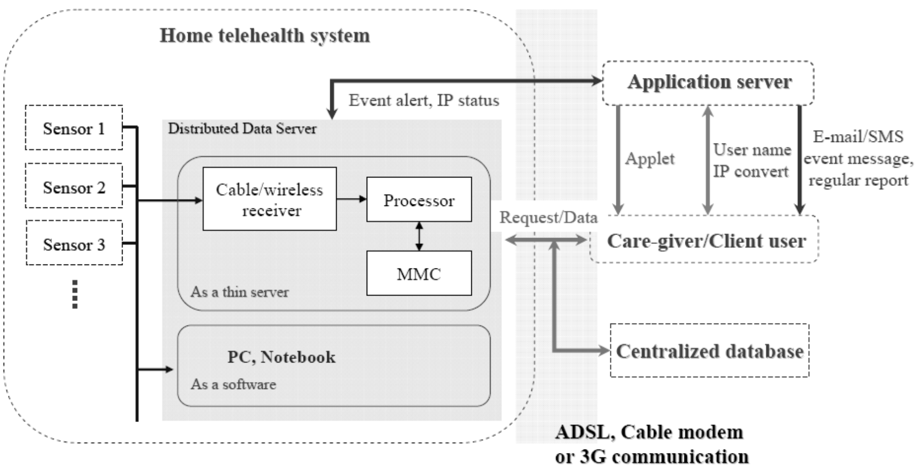

Fig. 2. Information structure of the decentralized home telehealth system

This is the smallest possible home telehealth system, which makes it economically viable and acceptable to the end-users. However, all technical functions of a centralized system, such as health monitoring data storage and display, health event alert, regular report etc., can still be achieved. Monthly service fee is not necessary, as the caregivers of the senior users (not the home healthcare service provider) take the responsibility of providing necessary care based on the health monitoring information. The DDS can still be connected to a centralized database when more complicated health management services are needed.

The emerging of a new class of computers – the so-called "Pad PC", is also a very important driver of CDF. Pad PC was called "tablet PC", "slate PC" or "screen PC". The industry is starting to consolidate its name into "Pad PC" after the successful launch of iPad by Apple Inc. in April 2010. Pad PCs are often small in size, equipped with a touch screen, and they are less expensive, more mobile than laptop PCs. Pad PCs usually possess less computation power than laptop PCs, and are designed to be used for specific purposes such as digital day planners, Internet surfing devices, project planners, music players, and displays for photos, video, live TV, and e-reading. Many PC manufacturers have planned to introduce new pad PCs after iPad in early 2011. Derived from DDS of the decentralized home telehealth system, CDF can be a hardware thin server or software. CDF is set up as PC software in this first stage. Pad PC is the major target platform for CDF. A dedicated CDF hardware device is also being developed.

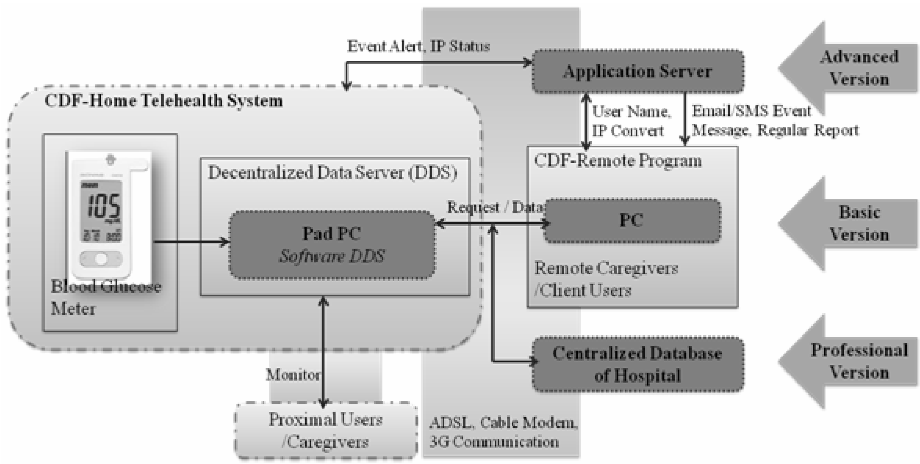

Fig. 3. The Information structure of CDF in 3 different versions

As illustrated in Figure 3, CDF software is offered in 3 versions. The "basic version" uses the simplest "stand-alone" information structure involving only two PCs on the Internet. CDF software is installed (in a pad PC) as software DDS in the home telehealth system for the senior user. Children/caregivers communicate with the senior user remotely by installing "CDF-Remote" program. The senior user uses vital sign meter at home. The measurement data can be transmitted to the pad PC, and saved in the storage unit. Children/caregivers can login into the senior user's pad PC using CDF-Remote program to track the health monitoring data of the senior user, and perform the 4 main functions of CDF described in the previous section. In the "advanced version", the users register in the application server shown in Figure 2 to perform the 4 functions of CDF from any browsers without installing the CDF-Remote program, and receive advanced services such as User name/IP convert, email/SMS event message, regular report etc. The "professional version" connects the CDF to the centralized database of a hospital or home healthcare service provider for users who need professional health care.

3 Software Design of CDF

Table 1 shows the 4 core functions of CDF, their sub-functions and descriptions. For designing the CDF software, the operation flow chart of CDF was first developed in Figure 4. Figure 5 shows the interface of the CDF, which incorporates mostly large,

Table 1. The Definition of Four Core functions

Category	Function	Description
A. Digital Photo Frame	A1. Display photos	• To display the photos of the specific folder. • Support the JPG, BMP, PNG 640 * 480dpi format of pictures. • Use timer to set up the play time.
	A2. Photos management remotely	• Via the Internet, remote computer management software uploads pictures to the system's memory card.
B. Home telehealth	B1. Blood Glucose/pressure device data access	• Through the transmission line, System connected with device and use the related protocol commands (provided by vendors) to get the physiological measurement data and stored in the system memory card.
	B2. Data browsing and analysis	• Displayed the physical measurement data on the screen and demonstrated its historical curve, mean, standard deviation, etc.
	B3. Data browsing and analysis remotely	• Through the management software, remote users can login to the system (must have account privileges) to browsing and analysis.
	B4. Data exception warning	• When the data exceed the normal range, system will automatically send the event alert messages by e-mail or phone message service (SMS) to the contact person (need to pay the fees).
C. Caring Messages and Reminders	C1.Caring messages and reminders checking	• Users are able to choose the type of event reminder and the time, which including 1. Medication reminder 2. Measurement reminder 3. Revisits reminded. When the time approached, the system will send a warning to user. • Remote users can also login to the system management software (must have account privileges) to set the event to remind user.
	C2. Reminding sound	• Sound of the reminder alert increase user's attention.
	C3. Leave the message/reminder remotely	• Remote users can login to the system through the management software (must have account privileges) to leave the message.
D. Entertainment	D1.Music playback	• Enable to play the music in the specific folder. • Audio format support for MP3 and other popular formats.

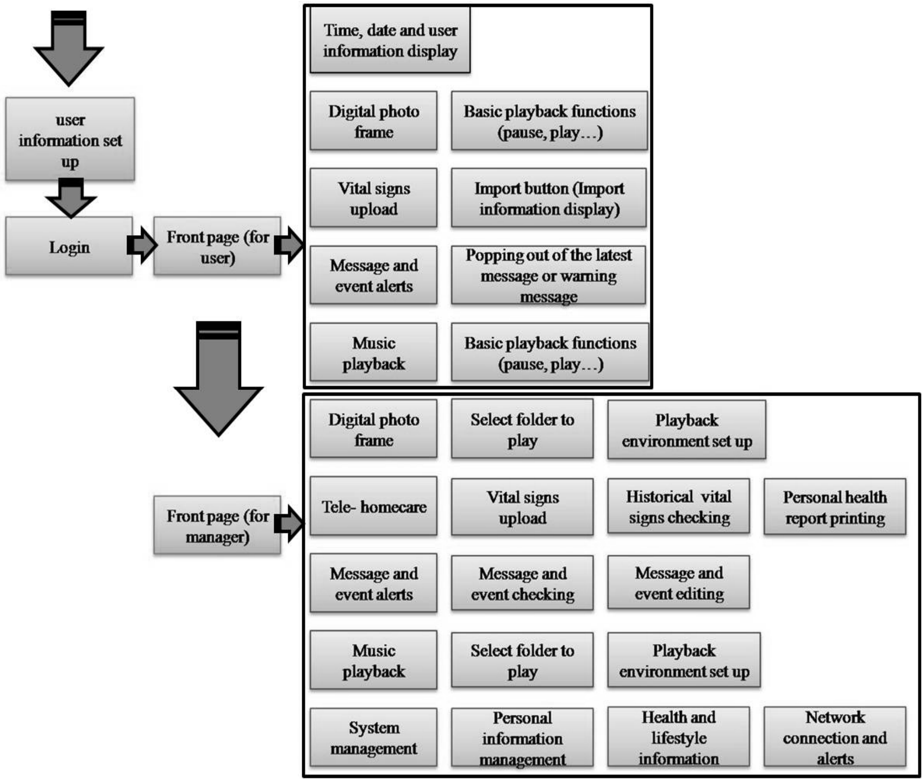

Fig. 4. Flow chart of CDF operation

Fig. 5. The Interface of CDF

graphical buttons. Designed as an information display channel, normally CDF works like a digital photo frame displaying photos and video clips managed by the remote children/caregivers. Message box pops up when there is a caring message or reminder.

The button at the lower left corner provides a one-touch operation for importing data from vital sign measurement devices, which is the only occasion the senior user has to operate the CDF. The button at the lower right corner leads to the management pages of the 4 main functions (Figure 6) for proximal users/caregivers who have more computer skills.

Microsoft Visual Studio 2008 is chosen as the CDF development platform. In order to facilitate system expansion and maintenance, all functions are written in modules. Currently, there are 10 modules in CDF program. Digital photo frame module, multimedia module, remote connection module, device communication module, drawing module, data access module, print module, message module, reminder module and network communication module.

Fig. 6. Management pages of the 4 main functions

4 Discussion and Conclusion

Although the usefulness of the home telehealth system has been recognized in many studies, and all technologies required are readily available, expectations for its widespread adoption have not been realized. In our observation, there is not a commercially successful home telehealth system in Taiwan.

Current models of home telehealth systems often involve in integration of different businesses and very complicated infrastructure. A monthly fee is required to cover the cost of maintaining such systems. However, the difference between the cost and “willingness to pay” for the current centralized service oriented model is huge. It is difficult to close this gap if the “customers”, including the patients, medical doctors, caregivers, do not have enough motivation to use such systems.

Competition in home telehealth system has moved from technical competition to finding the best business model. The CDF presented in this paper is actually our answer to the difficulties and challenges of home telehealth systems. The characteristics of CDF are summarized as follows:

(1) CDF is the smallest possible home telehealth system that can be established between a single user and his/her care giver without subscribing services and paying monthly service fee to a service provider.
(2) In addition to health data monitoring, children or caregivers can "deliver care" to their seniors not living together by warm messages and thoughtful reminders on the CDF, as well as sharing their feelings, joy, and life experience through photos and video clips.
(3) CDF is positioned as the software for providing care and positive emotion to elderly users, with the emerging new class of computers – the "Pad PC", as its major target platform.
(4) CDF creates a unique information channel for senior users who are not familiar with the operation of computers and Internet.
(5) With the different versions, CDF can still be used as a home station of the centralized home telehealth systems.

The development of the software version of CDF has been completed and is now under usability study. The interface has been examined from ergonomics point of view by inviting senior users to the lab to use the CDF interface. In order to be able to draw a significant conclusion on the acceptance of CDF, we are going to conduct an evaluation by the real users (senior, caregivers, and children) in their home environment, to evaluate criteria such as cost, utility, response time, flexibility etc., to compare with other existing telehealth systems. The basic version of CDF will be made available for free download after the preliminary user evaluation is completed.

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Utilizing Wearable Sensors to Investigate the Impact of Everyday Activities on Heart Rate

Leo Galway[1], Shuai Zhang[2], Chris Nugent[1], Sally McClean[2], Dewar Finlay[1], and Bryan Scotney[2]

[1] School of Computing and Mathematics, University of Ulster, Jordanstown Campus, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, Northern Ireland
[2] School of Computing and Information Engineering, University of Ulster, Coleraine Campus, Cromore Road, Co. Londonderry, BT52 1SA, Northern Ireland
{l.galway,s.zhang,cd.nugent,si.mcclean,d.finlay,bw.scotney}@ulster.ac.uk

Abstract. Advances in sensor technologies have provided the opportunity to perform continuous and unobtrusive capturing of physiological signals. One particular application that has benefitted from this technology is the remote monitoring and management of cardiovascular conditions. In this paper, details of an investigation considering the impact of everyday activities on heart rate are presented. ECG and accelerometer signals collected from wearable wireless sensors have been utilized to investigate the underlying relationships between physiological and activity-related profile information. The impact of activities on heart rate has been captured through analysis of the patterns of heart rate using the CUSUM algorithm. Subsequently, results have shown that a change in the pattern of heart rate is detected shortly after an activity commences. Further extensions of the research are also proposed, including integration of a range of ECG features and intelligent data analysis techniques, thereby facilitating the future development of context aware health monitoring mechanisms.

Keywords: Wearable Wireless Sensors, Connected Health, Wellbeing.

1 Introduction

Connected Health is an overarching concept that utilizes *Assistive Technologies* at its core in order to provide remote healthcare and wellness solutions for the purpose of maximising health and social care resources, patient self-management and patient engagement with healthcare professionals. Characteristically, *Point of Care* devices have been deployed within a patient's living environment to acquire and monitor physiological profiles, thereby facilitating remote monitoring and management of healthcare. By employing such devices, immediate access and analysis of the current health status of a patient has the potential to make it possible to detect and act upon the early stage symptoms of chronic conditions [1].

This paper presents the results from preliminary investigations, which have considered the underlying relationships between an individual's physiological and activity profiles. Data has been acquired from a number of participants using wireless sensor

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technologies during a predefined set of activities within a controlled environment. Based on the relationships between health status and performance observed during the completion of a range of everyday activities, an indication of an individual's health and wellbeing may be inferred [1-4]. Subsequently, it is anticipated that the discovery of such relationships may be further utilized during lifestyle interventions in order to enhance the overall health status of an individual, through, for example, the elimination of potentially dangerous activities for cardiovascular conditions based on key physiological patterns observed.

The organization of this paper is as follows: Section 2 provides a brief synopsis of related research, followed by a description of the methodology in Section 3. The results from the investigations, along with corresponding analysis, are presented in Section 4. Conclusions are drawn in Section 5.

2 Background

Within the Connected Health literature, physiological profile data has been employed either exclusively [5, 6], or in conjunction with activity profile data [2, 3], and environmental information [4], for a variety of purposes. These include analysis of the relationships between physiological and activity profile information [3], [5], and the classification and prediction of vital signs, activities of daily living, and health and wellbeing status [2-6].

Pawar *et al.* [5] conducted research into the use of physiological profile data for the classification of activities, employing a single-lead wearable ECG sensor, configured for Lead II, in order to obtain ECG data from a number of participants over a range of everyday activities. Principal Component Analysis was used to analyze motion artifacts inherent in the ECG signal, with the authors subsequently demonstrating the potential use of physiological data for activity classification. Similarly, Jakkula *et al.* [6] also utilized physiological information exclusively, in conjunction with Support Vector Machines, in order to classify and predict systolic, diastolic and pulse rate trends. Further extending the research, Jakkula [3] discussed the use of a K-Nearest Neighbor algorithm, featuring a binary taxonomy, for the classification and prediction of health status from both physiological and activity profile data.

The relationship between physiological and activity profile data, acquired using a single-channel ECG monitor with integrated 3-axis accelerometer over a range of activities of daily living, was also investigated by Yuchi and Jo [2] in order to perform heart rate prediction. Employing a feed-forward Neural Network to model the underlying relationship, the authors found that the predicted heart rate for the next time step was close to the actual heart rate and the model was potentially useful as an indicator for cardiac problems. In investigations by Jakkula *et al.* [4] lifestyle data, comprising a combination of physiological data, activity-related data and environmental information, was utilized in order to investigate the relationships between lifestyle and health and emotional wellbeing. Within the research conducted, the relationship was modeled using a K-Nearest Neighbor algorithm to classify and predict the future status of health and wellbeing of a single participant.

Within the literature surveyed, physiological profile data has been predominantly used for classification and prediction. Where physiological information has been exclusively utilized, research efforts have focused on the use of implicit features derived from the sensor data. Correspondingly, in the research presented herein, the heart rate has been obtained from sensor data however, such physiological information has been utilized alongside activity profile data in order to examine the effect on heart rate caused by the transitions that occur during various commonplace activities.

3 Methodology

For the investigations presented in this paper, the following set of everyday activities was defined: {*Ascend Stairs*, *Sit Down, Stand Up, Walk, Descend Stairs*}. The Shimmer wireless sensor platform was subsequently utilized to facilitate data acquisition during each participant's performance on the set of activities [7]. Employing two Shimmer devices placed on the upper-body and lower-body of a participant, physiological data was captured using the 3-lead ECG expansion module in conjunction with the device placed on the upper-body. The expansion module employs three recording electrodes to record bipolar leads in the Einthoven limb lead configuration. Due to restrictive cable length, the recording electrodes were placed in the left pectoral region to record variants of Lead II and Lead III. Both channels of the ECG data were sampled simultaneously at 100Hz [8]. Upper-body and lower-body activity profile data was simultaneously captured using the device's integrated 3-axis MEMS accelerometer, with a sampling rate of 50Hz and accelerometer sensitivity in the range [-1.5, 1.5] g [7]. In order to effectively detect changes in anterior-posterior and lateral movement, the upper-body device was placed in the middle of the participant's left pectoral, while the lower-body device was placed at the mid-point between the thigh and knee on the anterior of the participant's right leg. During the data capture phase of the investigations, three healthy participants, comprising 1 female and 2 males with no known cardiac conditions, performed the predefined set of activities five times each, resulting in physiological and activity information being captured from a total of 75 activities.

Pre-processing was performed on the raw data values acquired from the ECG sensor and accelerometers prior to data analysis. This aimed to reduce both the noise inherent in the devices along with the noise resulting from motion artifacts. For the ECG signal values, a Fast Fourier Transform was applied during pre-processing to attenuate low-frequency noise and waveform irregularities in the recorded signal. In order to obtain the heart rate from the ECG signal, automated R-peak detection was performed on the resulting ECG signal, using an adaptive filter with a threshold of 70% of the maximum level of the signal, and the average heart rate for each activity calculated from successive R waves. In addition, a low-pass filter was employed to attenuate frequencies above 20Hz from the raw accelerometer data. The resulting acceleration values were subsequently normalized to provide a direct mapping from accelerometer values to gravitational accelerations within the range [-1, 1] g.

Once each activity was completed, further analysis of the heart rate values obtained was performed using the statistical technique Cumulative Sum Control Chart (CUSUM) [9]. This was in order to reveal the significance of any relationships discovered between a participant's ECG data and the corresponding activity. By detecting shifts in the mean of a process, the application of CUSUM analysis to the heart rate values permits the discovery of changing patterns normally associated with performance on an activity [10]. Such patterns can then be used to monitor and identify any abnormal cases that may arise during the activity. Comprising a two-step process, the first step of CUSUM involves calculating the cumulative sum of the difference between the values of each data point and the process mean over time, where the process mean is the average heart rate value during an activity process, as given by equations (1) and (3). The difference between the maximum and minimum CUSUM values is calculated and utilized within a bootstrapping process to identify the change in the trend associated with the heat rate values. Once a change in the trend is evaluated as significant, a change point can be identified, thus splitting the set of data points into two segments with individual characteristics.

$$S_{diff} = S_{\max} - S_{\min} \tag{1}$$

$$\text{where } S_i = S_{i-1} + (x_i - \bar{x}),\ i = 1,\ldots N \tag{2}$$

$$\bar{x} = \sum_{i=1}^{N} x_i / N \tag{3}$$

The second step of CUSUM then identifies the point of significant change within the dataset, where the change point is the point at which the variance in the two segments is minimised [9], as given by equations (4) and (5).

$$\beta = \arg\min_k MSE(k) \tag{4}$$

$$MSE(m) = \sum_{i=1}^{m-1} (x_i - \bar{x}_1)^2 + \sum_{j=m}^{N} (x_j - \bar{x}_2)^2 \tag{5}$$

$$\text{where } \bar{x}_1 = \sum_{i=1}^{m-1} x_i \Big/ (m-1) \text{ and } \bar{x}_2 = \sum_{i=m}^{N} x_i \Big/ (N-m+1) \tag{6}$$

Whenever a change in the pattern of the heart rate had been identified during data analysis for each activity, the activity profile of the participant, contained within the acceleration data, was then utilized to provide contextual information regarding the possible reason for the change. Correspondingly, the point of transition within the activity profile is compared with the change point for the heart rate in order to reveal the underlying relationship between the physiological and activity profile for an activity.

4 Results and Discussion

Although data was captured over a total of 90 activities, only datasets collected from 55 activities contained usable information. This was partly due to communication issues between the wearable sensors and the receiving computer, and partly due to excessive noise within some of the captured signals. Nevertheless, the results

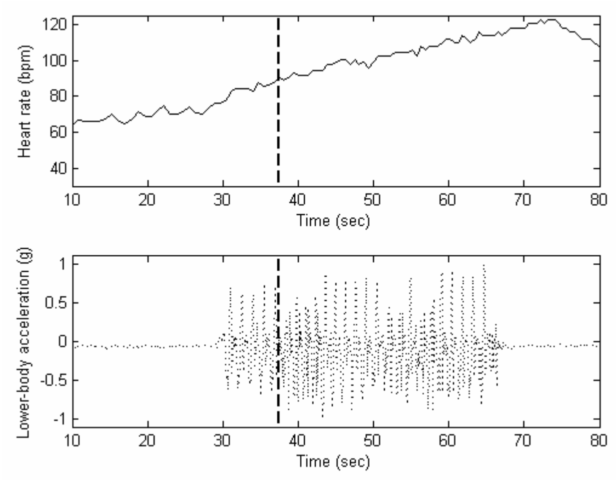

Fig. 1. Heart Rate (top graph) & Lower-Body Acceleration in y-axis (bottom graph) for *Ascend Stairs* with Change Point of Heart Rate Pattern denoted by dashed vertical line

presented herein will initially focus on the analysis of the *Ascend Stairs* activity, for which 93.33% of the data captured was usable. Figure 1 illustrates the sets of values for heart rate and lower-body acceleration obtained during an individual iteration of the *Ascend Stairs* activity by a single participant.

In Figure 1 it can be observed that the activity starts at approximately 30.00 seconds, prior to the detected change in heart rate pattern at 37.43 seconds. During the activity, the heart rate shows an overall increase and continues to increase for a short period after the activity has been performed, before it begins to recover to a resting rate. Correspondingly, the heart rate, in beats per minute, has a value within the range [63.34, 87.77] before the change point and a value within the range [89.04, 122.88] after the change point. Subsequently, the graph of heart rate values shows distinct patterns before and after the change point, thus depicting the change in heart rate in relation to the activity performed. A correlation between the heart rate values and the acceleration values can also be discerned. From Figure 1 the regular, repeated movements of the leg may also be seen in the graph of lower-body acceleration. As the stairwell used during the activities contained 3 flights of stairs with a small mezzanine level in-between each flight, the increased acceleration during the flights can be recognized in the acceleration graph. A comparison of the mean results obtained from all participants on the *Ascend Stairs* activity is presented in Table 1.

Each column of the table gives the mean start time of the activity ($Time_{Start}$), the mean time at which the change point was detected ($Time_{CP}$), the mean relative time of the change point ($Time_{CP\text{-}Start}$), the mean heart rate before the change point was detected ($HR_{BeforeCP}$) and the mean heart rate after the change point was detected ($HR_{AfterCP}$). The corresponding standard deviation values are given alongside each mean value.

Table 1. Comparison of Results from *Ascend Stairs*

	Participant 1 (σ_{P1})	Participant 2 (σ_{P2})	Participant 3 (σ_{P3})
$\text{Time}_{\text{Start}}$	31.00 (0.72)	30.85 (0.87)	29.94 (0.42)
Time_{CP}	40.42 (2.90)	37.75 (1.90)	36.27 (1.38)
$\text{Time}_{\text{CP-Start}}$	9.42 (2.39)	6.90 (2.53)	6.33 (1.46)
$\text{HR}_{\text{BeforeCP}}$	73.38 (8.04)	97.56 (8.42)	90.45 (16.0)
$\text{HR}_{\text{AfterCP}}$	107.56 (11.60)	122.53 (8.78)	116.15 (20.36)

In Table 1, it can be observed from the results for $\text{Time}_{\text{CP-Start}}$ that there is a close correlation between the time when the activity began and the time of the change point, with the change point having been detected shortly after the start of the activity. Subsequently, it has been shown that the transition to an activity results in a corresponding change in the pattern of the heart rate. This is likely due to the heart responding to the bodies increased demand for oxygen required to perform an activity. Although the differences in the mean start time of the activity, $\text{Time}_{\text{Start}}$, from each participant are somewhat marginal, a more significant difference may be observed in the corresponding results for the mean time at which the change point was detected, Time_{CP}, with the results from Participant 1 showing a slower change in the pattern of the heart rate than Participant 2 and Participant 3. Consequently, the values obtained for the mean heart rate before and after the change point, given as $\text{HR}_{\text{BeforeCP}}$ and $\text{HR}_{\text{AfterCP}}$ respectively, are also lower for Participant 1 than Participant 2 and Participant 3, suggesting Participant 1 has an improved level of fitness in terms of the heart's response to the given activity.

As an example of the results obtained over all activities, Table 2 provides the mean start time of the activity, the mean time at which the change point was detected, and the mean relative time of the change point, along with the corresponding standard deviation values, for Participant 1 (P1), Participant 2 (P2) and Participant 3 (P3). From 30 sets of activity data obtained from each participant, 90% of the data captured from P1 contained usable information, whereas 76.67% of the data captured from P2 could be utilized. By contrast, only 16.67% of the data obtained from P3 was valid. Subsequently, only data acquired during the *Ascend Stairs* activity is given for P3.

In Table 2, it may be observed from $\text{Time}_{\text{CP-Start}}$ that there is a degree of variation in the values obtained for the mean relative time of the change point over the five activities from P1 and P2. Nevertheless, comparing the mean start times of the activities with the corresponding mean times of the change points from the individual participants, given as $\text{Time}_{\text{Start}}$ and Time_{CP} respectively, it is apparent that a change in the pattern of the heart rate is detected shortly after an activity commences, regardless of the activity. Thus the relationship between the physiological profile and activity

Table 2. Comparison of Results from all Activities

	$Time_{Start}$			$Time_{CP}$			$Time_{CP\text{-}Start}$		
	P1 (σ_{P1})	P2 (σ_{P2})	P3 (σ_{P3})	P1 (σ_{P1})	P2 (σ_{P2})	P3 (σ_{P3})	P1 (σ_{P1})	P2 (σ_{P2})	P3 (σ_{P3})
Ascend Stairs	31.00 (0.72)	30.85 (0.87)	29.94 (0.42)	40.42 (2.90)	37.75 (1.90)	36.27 (1.38)	9.42 (2.39)	6.90 (2.53)	6.33 (1.46)
Sit Down	31.32 (0.55)	30.10 (0.14)	---	37.16 (1.43)	35.60 (1.35)	---	5.84 (1.01)	5.49 (1.24)	---
Stand Up	31.38 (2.31)	29.82 (0.29)	---	33.69 (3.66)	32.16 (1.00)	---	2.30 (1.65)	2.34 (0.72)	---
Descend Stairs	31.21 (0.62)	30.12 (0.58)	---	33.58 (1.11)	32.12 (0.59)	---	2.37 (0.82)	2.00 (0.60)	---
Walk	31.65 (0.66)	27.94 (2.56)	---	33.84 (1.25)	30.54 (3.24)	---	2.19 (0.70)	2.60 (0.74)	---

profile on everyday activities may potentially provide crucial information that can be further utilized in the development of algorithms that automatically monitor physiological status given the context from activity profile information.

5 Conclusions and Future Work

In this paper, preliminary investigations have been conducted that verify the ability to successfully capture changes in the patterns associated with heart rate, which occur as a direct result of performing everyday activities, through application of the CUSUM analysis technique. It is recognised that a limitation of the current work is the number of participants utilized. Further investigations should initially focus on an increased sample size, which includes participants with known cardiac conditions. Additionally, the research should be applied to a variety of features extracted from the ECG signal, by utilizing a more robust feature detection and extraction algorithm. Extensions to the research should also incorporate intelligent data analysis techniques for the modeling and classification of the activities based on the physiological profile information. Subsequently, mechanisms that provide context aware monitoring of health status, based on physiological information derived from sensor technologies may be further developed. Furthermore, in order to address the problem of incomplete datasets, due to packet loss occurring during the transmission of data, data analysis and communications protocol approaches may be adopted, thus providing additional areas in which to extend the current research.

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The Smart Home Landscape: A Qualitative Meta-analysis

Sam Solaimani[1], Harry Bouwman[1], and Nico Baken[2]

[1] Faculty of Technology, Policy and Management
[2] Faculty Electrical Engineering, Mathematics and Computer Science
Delft University of Technology, The Netherlands
h.solaimani@tudelft.nl

Abstract. Technological innovations, varying from ubiquitous computing, intelligent appliances, telecommunication, robotics, to wearable sensors, enable new Smart Home (SH) applications. More and more academic publications reporting on experiments on SH can be found. A comprehensive clustering of concepts and approaches is largely missing. Based on an extensive review of SH literature, this paper proposes a framework that decomposes the SH research into four domains and 15 sub-domains. The framework is applied to visualize the state of the art of SH research, and to outline future challenges. The framework helps researchers to identify gaps in SH research.

Keywords: Smart Home, qualitative meta-analysis, literature review, STOF model.

1 Introduction

Since the emergence of the Smart Home (SH) concept, more than 40 years ago, the concept has evolved from Domotica, to SH, and more recently to Smart Living (SL). The interest from industry in SHs is diverse. In construction (Domotica), a SH is seen as a house or living environment that contains the technology to allow devices and systems to be controlled automatically [7], [29]. Energy providers see opportunities for smart energy applications [23]. Telecom, Cable and Media companies, as well as hardware and content providers see opportunities for the home as an entertainment experience and gaming centre. Access providers see opportunities for managed IT services. Security providers see distant surveillance, control and safety equipment as an option for new business. In line with the concept of *Internet of Things*, the Information and Communication Technology (ICT) sector focuses primarily on innovative ICT-enabled solutions in order to improve connectedness of people and things, but also looks at entertainment and SoHo solutions [3]. Healthcare providers see the opportunities for sensor networks that will enable elderly and people with a chronic disease to stay longer in their personal environment, leading to cost reduction in the Medicare domain [5], [6]. Existing research on SH concepts are approached from a myriad of perspectives, e.g., users, organizational or technology; and various design issues are considered, including usability [22], security [10] interoperability as well as

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standardization [3]. Some of the recurring topics in SH area are remote management, interoperability, and context awareness. However, no overview over the SH research domain is available. Therefore this paper has as an objective to offer a meta-analysis of SH research and to initiate a discussion on topics that need further attention.

An extensive number of publications on SH is collected and analyzed in order to reveal the areas that are recurrently investigated and those that are neglected. In order to move from an exploration phase to an exploitation phase, SH research needs to be based on a coherent body of knowledge that cover not only technological and usability issues but also perspectives that discuss strategic collaboration between key actors, collective action and operational organizational issues. In order to reveal different components of and perspectives on SH concepts, an inductive research strategy is followed [20]. The literature review starts from four business model domains, i.e. Service, Technology, Organization, and Finance [4]. This model is, refined and expand based on the literature review. First, this paper provides a short discussion of the SH concept and proposes a working definition to confine the scope of the research domain. Next, the diversity of the SH domain is discussed and the methodology is described. Finally, we discuss the results and present the main conclusions.

2 Smart Home: Definition and Perspectives

Since the first official announcement of Smart Home in 1984 by the American Association of House Builders, the concept has been applied in different industry sectors. In this study, we follow a broad definition of Smart Homes as "*a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond*" [2, p. 1], and add *health, education* and *communication* as another need of the occupants to his definition. The last part of Aldrich's definition, "*connection to the world beyond*", makes it clear that the SH concept is limited, and the *SL* concept might be preferred, indicating that applications can be accessed remotely, or even distributed.

The fast-paced developments in technology, varying from ubiquitous computing [13], intelligent appliances [8], to robotics [21], wearable sensors [25], and so on, have created a new wave of interest in SL concept [21]. Others look at the SL area from a user-centric perspective and consider context and users demand as the leading factors for the development and provision of SL concepts [2], [11]. The organizational perspective is yet another lens. A core question is for instance, how different providers align their strategic and operational processes in SL Eco-Systems in order to provide viable and feasible SL concepts and Business Models [24].

Different Critical Design Issues (CDI's) have to be considered in the development and provision of SL concepts. CDI's are variables that are perceived to be of eminent importance to the sustainability of the service or product under design [4]. CDIs originate from different disciplines, i.e. service innovation, marketing, technical architectures. Some examples are ease of use for user- [17], standardization (e.g. ZigBee, OSGi), user experience in SL labs [19], and security [10]. This paper shows to what extent, industry domains and CDI's are covered in the SH literature.

3 Methodology

First a list of relevant publications on SL, by making use of web and search engines like Google Scholar, Web of Science, and Scopus, was compiled. Search terms mentioned in title, abstract or as a keyword and that are interchangeable with SL like home automation, ambient intelligence, and smart/intelligent home(s) were used. Publications from a wide variety of academic publishers for example Elsevier's Science Direct, Springer, JSTOR, ACM, IEEE Computer Society, Wiley Human Technology, Social-Informatics and Telecommunications Engineering were found. This yielded a sample of 62 publications. The selected publications were then inspected in terms of relevant references (snow-ball sampling). The final collection contained 93 publications. Next, the publications were subjected to a full-length screening. The core concepts discussed in these publications are summarized in a mind-map. Core concepts were identified by focusing on 'hypothesis', 'research questions', and 'theoretical concepts'. We started the mind-map with four general domains borrowed from STOF framework [4]. These domains can be shortly defined as follows. The service domain offers a description of the value proposition (added value of a service offering or products) and the market segment at which the offering is targeted. The technology domain describes the technical functionality and architecture required for service or product offering. The organization domain describes the multi-actor value network required to create, manage and distribute the service/product. The finance domain gives a description of the way a value network intends to generate revenues and of the way risks, investments and revenues are divided across actors. These four domains were the starting point for "clustering" the existing literature. The four domains were inductively, modified, refined and detailed, with as a final result a tree of topics that belongs to a specific domain. As suggested by [20] each article forces the researchers to reconsider the tree and its branches, and adapt (i.e., modify, refine or detail) when needed. The final representation of the clusters is similar to the content-analytic "Dendrogram" method, from [16]. XMind software is used to make an advanced cluster-based mind-map in a structural way. To increase the internal validity both authors have reviewed the publications, codes and clusters, and discussions took place to reach consensus on the final clusters.

4 Results

In this section all clusters are depicted and discussed for the four domains separately. The mind-map contains the four general categories we started from, 15 core categories and several sub-categories. For the sake of readability, no more than two layers are presented, with the exception of interoperability, agility, usability and usefulness. These four technology clusters are depicted three layers deep. In this way we were able to visualize the technology-related topics in a mind-map[1].

4.1 Service Domain

In the service domain the customer value of a product of service that a provider or network of providers offers to meet the customers' needs, is described, analyzed or

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[1] To keep the paper within the requested number of pages, the literature reference in this section are excluded. A full version with the literature references can be requested from the corresponding author.

defined. The customer value is determined by non-technical elements, such as value proposition, service delivery, distribution channels, after-sales services. The identified clusters are: Market segment, Service definition, Service provision, and User adoption (Fig. 1). From a service perspective, some publications consider the issue of market segment by looking at the structure of family; daily routines; their demographical location; the type of dwelling they are living in; or, the buying power of their customers, e.g., dual income or single income.

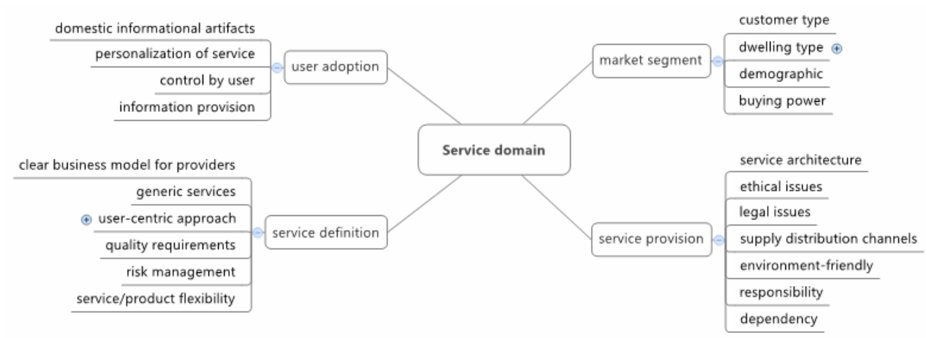

Fig. 1. Service domain

Some articles aimed at defining and providing a service in terms of business model, generic services and service distribution channels, definition of quality requirements, risk management, service flexibility, ethical and legal issues, responsibility and dependency created by services, and environmental-friendly service provision. A sub domain focuses on service definition in a user-centric way. Factors like usability, usefulness and contextuality in ethnographical terms rather than technical design or technical development are some main topics.

Like user-centric approach, user adoption is also discussed from both technical and non-technical point of view. A number of non-technical factors marked as essential to user-adoption are user in control, service personalization, information provision to customers, and the informational home artifacts, e.g., invitations, bills, appointments.

4.2 Technology Domain

The technology domain contains the most numbers of publications, and discusses a large number of technical-related issues. These issues serve as enabler of, or driving force behind many SH innovations. The four central clusters of this domain are Human-Computer Interaction (HCI), smart technologies, application areas, and technical requirements (Fig. 2).

HCI: One HCI-related topics is the interactional affordance, which not is only concerned with usability, but also with usefulness. On the usability side topics like ease of use, e.g., easy installation or control, and satisfaction; interface design, interaction design principles, and interface personalization are discussed. Usefulness should be improved by: social connectivity, service laborsaving qualities and good parenting facilities, location-based services, assistiveness, and sense of control. Augmented reality has to be integrated with the existing home artifacts.

HCI literature discusses prototyping, as well as design methodologies, but the focus is in many cases on SH laboratories. Some examples are: The Aware Home, comHome, LIVEFutura, PlaceLab, the Gator Tech Smart House, Vallgosson, iHome, House-n-Consortium and Ubiquitous Home. These are artificial home imitations, used to evaluate and analyze new and existing technologies, user's demands and behaviors.

Another HCI-related item is user context or context-awareness. The context depends on the location or situation of users like being home, at their office, or being in a state of urgency, feeling and behavior, and user's habits and personality.

Fig. 2. Technology domain

Technical requirements: Several publications are pointing towards technical requirements, such as privacy and security, reliability and manageability, flexibility, upgradability, replicability, adaptability, extensibility, maintainability, non-obtrusive, adaptability, anticipatory, scalability, and elicitation of requirements. Two of the most frequently discussed technical issues are interoperability and standardization, and related topics such as protocols; context-aware, ontology-based, agent-based, goal-oriented, and/or service-oriented middleware. System and software-, hardware-architecture, service-, middleware-, and logical-architecture are discussed.

Application area: The technologies are applied in very diverse areas, varying from health SHs, medical, energy, education, shopping, mobility, to home control.

Smart technologies: Some publications are dedicated to various smart technologies, approaches or services like: health, sensor technology, wearable technologies, smart home-devices, sustainable-energy technologies, mobility, artificial intelligence, and robots.

4.3 Organization Domain

The design, development and provision of a service or product require involvement of organizations from various industry sectors. The involved providers work together not only to complement each other, but also to create value for their customers in a way that otherwise would not be possible. The organization domain focuses on topics that are relevant to the emergence and governance of such value networks. Within the scope of this domain three clusters are relevant. One is the coordination of collaboration sectors, i.e., tight coordination versus loose coordination. The viability of business model is another discussed factor, which impacts service commercialization and partnership. Also technological and organizational alignment is discussed. On the other hand, business model viability depends on service maintainability, type of innovation, i.e., open versus close innovation and division of roles. The last cluster identifies the multidisciplinary characteristic of the SH industry, discuss requirements of relevant stakeholders, expectations of the eco-system including users, collaboration issues on providers' side, and academia-industry relationship.

4.4 Finance Domain

The financial arrangements between all actors of eco-system (i.e., providers, suppliers, manufactory, customers etc.) are the bottom line of the finance domain. Topics such as revenue, cost, investments, financial risks, pricing, and performance indicators are some typical examples of finance domain. Four clusters are identified (Figure 3). Attention is paid to financial analysis, i.e., cost and benefit analysis, from both perspectives, i.e. providers and customers. The providers have to analyze the short-term and long-term effects of investments, and consider affordability of SL services for the customers. In addition, the creation of financial benefits in terms of financial saving, improved efficiency, for example in health monitoring, and use of new communication channels has to be taken into account. There is an increasing demand based on financial motives, such as investments in green ICT, teleworking, e-health, e-commerce, the growing aging problem, and the technology advancements that decreased the costs and makes it easier to provide more advance innovative service for lower prices. [1] emphasize the new wave of economic order, characterized by *experience economy*, i.e., people are willing to spend money on having experiences; the *creative industries*, and *co-creation*.

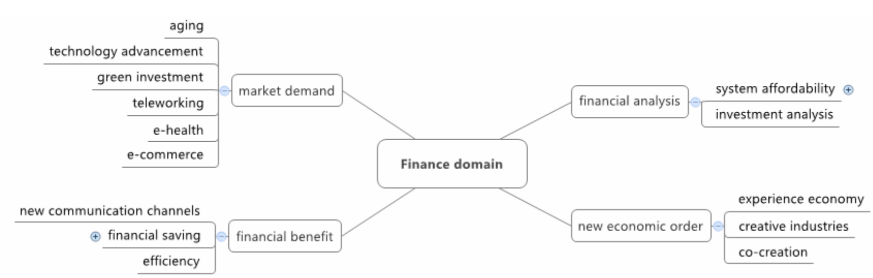

Fig. 3. Finance domain

5 Discussion and Conclusion

At a glance, the un-proportionally distribution of the four clusters attracts the attention. The technology domain is by far the most prevalent domain covered with a high-level of detail as indicated by the multi-layered clusters and multiple publications on same or similar topics within a cluster. In contrast, a limited number of non-technological topics have drawn the attention of SH researchers. Most topics in non-technology domains are covered by a single publication. So, contradictory to the repeated reminder of several researchers, SL sector is still primarily dominated by *technology-push* [11], [2], [1]. Increasingly, more user-centric approaches are applied in order to reveal the (tacit) demand of the user [9], [26], [27]. However, these user centric research projects are often closely related to research focused on technical requirements. Little attention has been paid to the managerial (i.e., service and finance domain), and organization topics, like strategic collaboration, collective action issues, role of dominators or keystone players in SL Eco-systems, alignment of operational processes of service providers involved in developing and implementation of SL concepts, information and value exchange.

Possible alternative explanation can be offered for the lack of attention to more socio-technical issues. First of all the domain of SL is still a domain of technicians. Next it can be observed that it is easier to acquire funding to conduct technical research and experiments, for instance the EU FP7 program fund a number of projects with a strong focus on technology for SL and eHealth. It is also easier to get papers acceptance by mono-disciplinary journals, than in multidisciplinary ones. Moreover there are more technical-oriented conferences and conference tracks, which again stimulates the virtuous technical cycle, i.e. a typical example of positive network externalities. Finally, SH projects and experiments are pre-dominantly conducted in an R&D environment, and not guided or yet taken over by profit-driven firms. The fact that SL is still in an exploration phase [12] can explain the fact that more socio-technical and economic studies are not yet available. At the other hand, the fact that SL concepts are not commercially exploited makes it clear that there are apparently a lot of issues from a strategic, organizational and financial perspective that needs further attention. The vision that Mark Weiser [28] introduced two decades ago, of a world where tons of interconnected intelligent devices and networks serve human in an unobtrusive way, is although slowly progressing, still no reality. Despite the overwhelming technology advancements in the recent years [1], the diffusion of SH products and services are still far from common reality, and a large-scale commercialization cannot be observed.

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Using Code of Colors through ICT and Home Automation Technologies in the Housing Environment Context for Persons with Loss of Autonomy

Marie Delvigne[1], Anaïs Santos[1], Aurélie Tardot[1], Maxime Devilleger[1], Adrien Fortin[1], Thomas Maitre[1], Guillaume Latron[1], Aurélie Bernard[1], Morane Gache[1], Mathieu Pastier[1], Laurent Billonnet[1], Emmanuel Desbordes[2], Jean-Michel Dumas[1], Bruno Fayette[3], Michelle Denis-Gay[3], and Aurély Dussartre[4]

[1] University of Limoges, Limoges, France
[2] Jean Favard High School, Guéret, France
[3] CNISAM, National Center for Innovation in Health, Autonomy and Trades, Limoges, France
[4] Soins et Santé therapeutic day-care center, Limoges, France
laurent.billonnet@unilim.fr

Abstract. The appropriation process of the environmental space parameters by elders can be done through the use of color codes that are meaningful to the persons with loss of autonomy. This approach is based upon the natural interpretation of communicating signs and signals by the brain that helps to answer more quickly to critical situation at different degrees. We illustrate first with the transposition of the color codes used in the automobile domain to the housing environment. By extension, we show that intelligent furniture can be designed through ICT and home automation to assist persons with cognitive troubles or motor disability. Finally, we describe the application done in a dare care center for persons with cognitive troubles. Colors of the rooms have been chosen to allow the patients to naturally identify the role of each room.

Keywords: color codes, ICT, home automation, assistance, cognitive troubles.

1 Introduction

The persons with loss of autonomy have several sociological and psychological blockings in using the technologies aimed to reduce their dependence. Very often, these blockings are associated with cognitive or visual troubles thus increasing the non appropriation of the technological assistance. It is thus necessary to propose non intrusive and non stigmatizing schemes to allow these people to appropriate more easily the home automation and information technologies equipments installed in their housing environment. A global solution is linked to the communication with the environment and the appropriation processes through the use of color codes meaningful to the persons with loss of autonomy. This approach is based upon the natural interpretation of communication signs and signals by the brain that helps to answer more quickly to critical situation at different degrees.

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Several research projects in association with the University of Limoges [1] are developed using this principle. First, a possible transposition of the assistance and security in the automobile domain [2] to the housing environment is shown. By extension, we show that intelligent furniture can be designed to assist persons with cognitive troubles or motor disability using the same methodology. ICT and home automation equipments can then be used to augment the natural functionalities of classical furniture.Finally, we describe a collaboration we have with a dare care center for persons with cognitive troubles. In this medical center, colors of the rooms have been chosen to allow the patients to be guided and to naturally identify the role of each room.

2 Color Codes as Intuitive Indicators

2.1 Color Code and Space Perception

To limit the risk of driving accidents, car manufacturers have created particularly effective signage system by developing many visual and audio codes. Since the beginning of the automobile, colors and interpretations related to certain markings are naturally accepted as logically linked to an innate interpretation of the brain. The validation of these color codes is effective, in particular for the codes based on the colors green, orange and red.

These color code appeared for the first time in London on traffic lights, and arrived in France in 1920. It is now used internationally, so a driver can understand the driving rules around the world. The dashboard of the car perfectly integrates a set of logos based on these three colors. The brief appearance of a logo using one of these colors activates an immediate reaction of the person. Red means an immediate danger. It was chosen for its symbolism (blood, death) and because it is quickly visible and identifiable. Green is indicative and tolerant, opposite and complementary to red from a chromatic point of view, which also makes it highly visible and easily identifiable. Moreover it is a median color, often associated with health. Orange replaces the original yellow finally judged visually too aggressive. It is situated between the red and green on the color wheel. It is a very bright color that evokes heat and brings a dynamic and immediate response. It stimulates the brain and requires increased attention. It is often used in road safety (traffic lights, traffic officers' clothes, signs and signage...).

The color code now overcomes the frame of the automobile and becomes a way of perceiving the environment in the daily life. It indicates a way of perceiving space. It is thus interesting to study the transposition of this code and related logos to reduce the loss of autonomy in the housing context. Indeed, even if some people have trouble apprehending and understanding space, they know the symbolism of colors and can take advantage of color properties within their immediate environment in particular for those with visual or cognitive impairment. People with Alzheimer's disease get lost very easily; they cannot find their way and are not always aware of the danger. Thanks to well-chosen colors, they can orient themselves and understand where they can go and where they should not go.

Similarly, for the persons with visual loss, color is an additional indication in the smooth process of environmental perception. Placing the red color on daily objects will prevent from danger. The orange color will alarm from a potential danger, and the green color will indicate a secure state or use. If the threshold of a door is painted in orange, the person will know intuitively that he must be prudent. Objects (e.g. kitchen items) or red household appliances will be understood as at risk. Floors or pathways painted in green will indicate the way to go safely. Thus a person who tends to forget how to get in the bathroom or who is simply disoriented (especially at night) may, thanks to a colored pathway, recover its independence at day and at night.

2.2 Chromic Materials

Chromic materials (also called “X-chrome” materials) are smart materials which color changes reversibly according to various stimuli applied (heat, humidity, pressure, electricity, light...). They may translate a change in one environmental parameter for preventive information. In particular, thermochromic materials (inks, paints, micro capsular coatings) have the ability to change color depending on temperature. They can be used to prevent the dangers of burns. This technology can be very accurate to the nearest degree. These materials are currently already used as temperature indicators of functioning, for example inside fridges or on the bottom of a saucepan or a skillet. They may also be considered as a coating inside a bathtub, which tells whether the water is hot or cold.

2.3 Light as Information

Light therapy is used in problems of dementia for the elders. Anglo-Saxon studies have shown that the effects of light decrease the symptoms of cognitive disorders and improve sleep. To attract attention and inform on an environmental parameter, several techniques exist. For example it is possible to associate a color code to a light gradation system. This gradation can concern the light intensity itself, but also the color or saturation, or the rate of flashes emitted in a given color. These types of gradations of light inform people about an impending danger or its importance level. This system can be used to overcome the forgetfulness of the elderly or people suffering from Alzheimer's disease. For example, a pilot light on a kitchen oven indicates a normal cooking operation mode when green. The light changes to orange a few minutes before the end of cooking, and then turns to red when the bell sounds the end of cooking. The rhythm of the flashes emitted would increase with the time elapsed until the opening of the oven. Another example concerns a light shower head that visually helps to evaluate the water temperature. Once the water is poured, the shower is activated and illuminates the water with its 15 LEDs. Beginning with the green, it will change to orange and finally red as we increase the temperature of the water. LEDs are small self-powered through a dynamo that is activated when the water flows.

3 Smart Furniture Using Color Codes

Another project is driven in association with the CNISAM (An innovation pole for health, autonomy and trades [3][4]). Three furniture items are under consideration: a “smart” bedside table, a bed for child under three years suitable for parents with disabilities, and a closet/dressing increased with home automation functionalities. This furniture is meant to be prototypes which will inspire designers and carpenters in making furniture for people with disabilities. Color codes will be applied to guide and inform the user on the role of the different parts and equipments of the furniture.

The most illustrating example of the color codes application deals with the design of a bedside table which purpose is to make life easier for disabled people during the night. Compared to a conventional bedside table, the prototype integrates a backlight that illuminates the bedside table at the touch of the user to help him locate things on the table (water bottle, glasses...) during the night. The prototype is also able to communicate with different equipments (roller shutters, heating, lighting, light paths...) as a central home automation command center.

In addition to the functionalities added through ICT and home automation equipments, a color code (derived from the green/orange/red code) has been established to differentiate the drawers and help people suffering from cognitive disorders or vision problems. The objective being mostly to guide and help the user rather than preventing from a danger, a 4-color code (Table 1) has been chosen to assist the disoriented person during the night. As shown in figure 2, the orange color has been replaced by the yellow color to indicate an intermediate state of process as a warning indicator. The blue color works together with the green color to show the availability of equipment or a function not in use.

Table 1. The 4-color code used for the furniture projects

Red	Green	Blue	Yellow
bad usage / non availability of the equipment / critical importance or use / problem with the equipment or function	good usage / availability of the equipment / normal functioning or use / in function	soft indicator showing the availability of a equipment / the equipment is not in use or is in stand-by state	intermediate state – needs an action from the user to be in normal use, return to normal state or finish a dedicated action / warning indicator

In addition, the bottom drawer is accessible for wheelchair users through a system of enhanced raised drawer. An integrated automated pillbox will guide the user in taking his medications and treatments. The same color code can be applied to the pillbox to indicate a good use in time of the medicines.

4 Color Codes as Guides for Persons with Cognitive Troubles

The “Soins et Santé” (Care & Health) association [5] is non-profit medical structure which mission is to maintain and improve the quality of life for patients at home. The structure includes a therapeutic day care center offering many activities such as memory, gymnastics, gardening, and multi-sensory stimulation workshops to help patients find their way into space and maintain their independence.

In some structures, demented patients carry a wireless device (bracelet, pendant…) that triggers an alarm when the patient goes to a non-authorized zone. “Soins et Santé” association has chosen to implement technical solutions enabling the secure monitoring of patients through indirect control of the employees. A disposal for patient safety has been established for simultaneously securing sensitive premises (offices, treatment rooms, utensils and care products storage places). The goal is to allow safe and non-controlled natural ambulation of the patients, respecting their integrity, and thus defending the values of respect for the human person. The use of proximity card readers now combines convenience and traceability. With the new system, monitoring and activity logs of staff are continuous and automatic, thus freeing them of a heavy workload with benefit for the patients.

Other benefit has been taken from a “color scale” that has been established to help the patients to naturally identify the role of the different rooms within the structure. The indoor space has been thought to correspond to a prosthetic healthcare architecture and to reduce the incidence of behavioral problems as "protective factor". Adapt the architecture to the needs of patients allows them to roam freely without risk, and to stimulate their faculties. Light, colors, choice of equipment and furniture in terms of ergonomics also participate in the welfare of residents, carers or patients. The diversity of places and environments facilitates the tracking and facilitate the identification features of each room for the patients. In particular, a multi-sensory room allows residents to train their senses quietly and peacefully. The main classical light (on or off) was particularly unsuitable to the dedicated activities. Brutal lighting at the end of an activity session dazzled patients and could disorient even leading them to lose balance. The use of LED mood lamp allows a gradual return to a non-aggressive normal brightness level without risk of glare or disorientation.

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The COSE Ontology: Bringing the Semantic Web to Smart Environments

Zachary Wemlinger and Lawrence Holder

School of Electrical Engineering and Computer Science
Washington State University
Box 642752, Pullman, WA 99164-275
{zewemli,holder}@wsu.edu

Abstract. The number of smart appliances and devices in the home and office has grown dramatically in recent years. Unfortunately, these devices rarely interact with each other or the environment. In order to move from environments filled with smart devices to smart environments, there must be a framework for devices to communicate with each other and with the environment. This enables reasoners and automated decision makers to understand the environment and the data collected from it. Semantic web technologies provide this framework in a well-documented and flexible package. In this paper we present the Casas Ontology for Smart Environments (COSE) and accompanying data from a test smart environment and discuss the current and future challenges associated with a Smart Environment on the Semantic Web.

Keywords: Semantic Web, OWL, Ontologies, Smart Environments, Ubiquitous Computing.

1 Introduction

The concept of a smart environment necessarily requires a multitude of sensors in order to determine the environment's state and take action as necessary. Real-world devices available now range from smart phones to intelligent dishwashers. This heterogeneity among devices has led to a fractured sensor landscape. Because of this, the machine learning algorithms and reasoners currently used in smart environment must be tailored to a specific set of sensors. Such tight coupling inhibits the deployment of new technologies into the environment, which in turn significantly reduces the environment's long-term usefulness. In order to address this, smart environment data should be mapped to a set of core semantics which can be used by agents and algorithms to operate in a variety of environments. An example of this would be the mapping the output of a gyroscope to the concept of angular acceleration. Activity recognition algorithms learning in this context can focus on the semantics of motion and interaction, without becoming dependent on a specific set of sensors.

Ontologies provide a method to maintain facts about the nature of the world in a logical form. Common-sense ontologies codify the general nature of things, e.g. that water is a liquid and liquids are amorphous. Naturally, these ontologies are very large

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and require significant computing resources to fully utilize. In order to minimize the computing resources required for a smart environment, we propose extending these ontologies with ontologies smaller smart-environment focused domain ontologies using the Semantic Web [10]. Using this hierarchical approach we can minimize local computing requirements without sacrificing useful general knowledge. Our contribution here is to present a smart environment domain ontologies with mappings back into the OpenCyc[12] common sense ontology.

2 Ontological Reasoning

The term ontology can, at times, be ambiguous. One of the most well cited definitions for the use of the term in Computer Science is that an "ontology is an explicit specification of a conceptualization" [6]. The curious reader is encouraged to also read [9],[8],[5] for a more comprehensive discussion of what exactly constitutes an ontology. In this paper we will use the term "common-sense ontology" to refer to an upper ontology which provides general knowledge not specific to smart environments. Domain specific ontologies specify the concepts for a given domain. The full topic of ontological reasoning is well beyond the scope of this paper; rather herein we will describe the practical uses of ontological reasoning in a smart environment.

3 Previous Work

Using ontologies in smart environments has been discussed before in [16],[2],[1],[15],[7],[11]. Each such proposal and experiment uses a different ontology with differing purposes. Unfortunately, these ontologies are not interoperable in the same way that differing syntactic protocols are not necessarily interoperable. Moving knowledge from one ontology to another requires mapping those two ontologies. Automatic ontology mapping is still an active research area and manual mapping is a time-consuming process. Also, domain ontologies do not cover the kind of common-sense knowledge that can enable a smart environment to interact naturally with a resident.

This provides the impetus for the use of common-sense knowledge bases as a basis to standardize common terms used in domain ontologies. Well known upper-level ontologies include Cyc [12] and the DOLCE [4] suite of ontologies. The massive effort required to build a comprehensive upper ontology naturally limits the number of them available. Using OWL ontologies [13] we can manually map from a domain ontology into one of these larger common-sense ontologies. This allows those developing ontologies for smart environments to focus their efforts on environment modeling rather than modeling the universe in general.

4 The COSE Ontology

As mentioned previously, there are other ontologies for smart environments proposed in the literature. None of these can be directly accessed via a URL, and thus by a reasoner, which prevents them from being extended by other ontologies. In order to

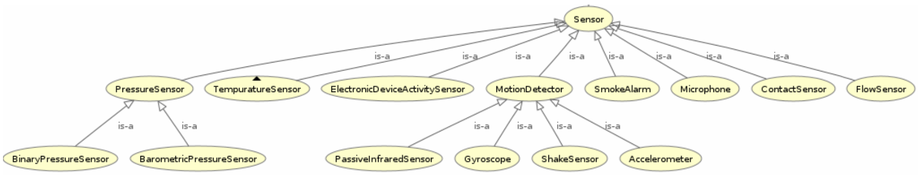

Fig. 1. Sensor hierarchy in COSE

address this we have developed the Casas Ontology for Smart Environments, or COSE. This ontology is available at http://casas.wsu.edu/owl/cose.owl. This ontology conforms to the OWL Lite profile. The main concepts in the COSE ontology are: buildings, occupants, sensors and human activities. Figure 1 illustrates the sensor class hierarchy.

We have also defined a mapping from concepts in COSE which are also present in the OpenCyc ontology. OpenCyc is a subset of the full Cyc knowledge base which has been made available under the Apache License, Version 2. This mapping is made available in a separate ontology because the mapping uses the owl:sameAs construct. This construct is only available in the OWL DL profile which is computationally more complex than OWL Lite.

In addition to COSE, we have developed an ontology[1] for the Kyoto smart apartment test bed. In this ontology we define only typed instances of object classes in the COSE ontology which are present in the Kyoto test bed. We have chosen to put these individuals into an ontology rather than RDF because they describe the environment rather than the state of the environment. The Kyoto testbed was chosen because there is a significant amount of published data available for this environment. We are in the process of converting this data into RDF format utilizing the COSE ontology. The first converted dataset is available at http://casas.wsu.edu/rdf/adlnormal.n3. This dataset contains 38,910 triples pertaining to 51 participants performing 5 activities. The data was taken as part of the experiment described in [3]. A sample of this dataset is presented in figure 2.

```
<p01> rdf:type cose:Occupant ; .
<p01.t1> rdf:type exp:Task13;
cose:activityInvolvedPerson <p01>; .
<M08_2008-02-27_12:43:27.416392>
  cose:dataSourceSensor kyoto:M08 ;
  cose:timestamp "2008-02-27 12:43:27.416392" ;
  cose:sensorInState cose:SensorOnState ;
  rdf:type cose:sensorChangeState ;
  cose:sensorMeasurementRelatesToActivity <p01.t1> ;
  cose:sensorMeasurementRelatesToPerson <p01> ; .
```

Fig. 2. A sample of the adlnormal dateset expressed in Notation 3 syntax

[1] Available at http://casas.wsu.edu/owl/kyoto.owl

5 Future Directions and Challenges

In addition to these ontologies, we have begun work on semantically describing activities of daily living and the steps required to complete them. The ontology for this is available at http://casas.wsu.edu/owl/activity_experiment_1.owl. The adlnormal.n3 dataset depends on this ontology to provide a description of the tasks involved in the experiment described in [3]. This ontology is still in development and will be extended to provide a richer model of the tasks involved.

There is currently a lack of AI learning toolkits which natively support RDF data and OWL reasoning. While there are a number of tools for OWL reasoning, e.g. the Pellet reasoner [14], as well as RDF storage and querying; what is needed is a method for easily joining these tools to a learning agent. This is one of our directions for future research.

One of the open problems in smart environment research is activity recognition which essentially maps environment states to some semantic understanding of what is happening. We see this work as a synergistic parallel effort to activity recognition.

6 Conclusion

Smart environments are quickly turning into reality. In order to fully realize the potential of these technologies, devices must be able to communicate both syntactically and semantically. The Semantic Web provides a well-researched basis for the exchange and use of semantic knowledge. Using a hierarchical approach when defining the ontological basis for reasoning in a smart environment allows for extensive re-use of work and light-weight ontologies suitable for embedded environment reasoners. Our goal here is to lay a base to enable further work in this area.

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Portable Ambulatory Urodynamics Monitoring System for Patients with Lower Urinary Tract Symptoms

Keo-Sik Kim[1], Chul-Gyu Song[1], Jeong-Hwan Seo[2], Min-Ho Kim[1], and Sang-Hun Ryu[1]

[1] Chonbuk National University, Jeonju, Republic of Korea
{keosikis,song133436,minhok84}@gmail.com,
noseen@naver.com
[2] Chonbuk National University Hospital, Jeonju, Republic of Korea
vivaseo@chonbuk.ac.kr

Abstract. A fully ambulatory urodynamics monitoring (AUM) system was developed in this study. Conventional cystometry (CMG) and AUM were performed for 28 patients with neurogenic bladders caused by spinal cord injury (24 males and 4 females, age: 49.4±13.9 years, BMI: 23.5 ±2.4). As a result, 10 of the patients were diagnosed as having different reflexibility of the bladder between conventional CMG and AUM (p<0.05), and in the patients with areflexic bladders the number of patients with detrusor overactivity was higher in AUM and leakage was observed more frequently. These results demonstrated that our system could be a useful additional tool in the clinical assessment of patients in which CMG failed to explain their symptoms.

Keywords: Ambulatory urodynamics; portable instrument; health monitoring.

1 Introduction

Voiding cystometry, which is a part of an urodynamics study, involves the continuous measurement of the pressure/volume relationship of the bladder and evaluates sensation, detrusor activity, bladder capacity and compliance [1]. In conventional cystometry (CMG), the bladder is filled with saline at rates of up to 50 ml per minute to assess filling and voiding bladder functions in a retrograde manner. However, this method is difficult to evaluate the physiological functions of the storage and voiding of the bladder, because of the artificial method of filling that is employed. On the other hand, ambularoty urodynamics monitoring study (AUM) enables the bladder to fill naturally through natural metabolic functions. This natural filling of AUM allows the bladder function to be assessed in a more natural physiological manner, in which the pressure is measured while the bladder is distended gradually by the urine secretion of the patient. Several researchers reported on the availability and reliability of AUM compared to CMG [2]. Accordingly, we developed a fully AUM system based on a hand-held computer, as considering the potential of AUM and the possible advantages of enabling the patient to be completely mobile during the study. Our system was designed to enable the time at which various events, such as the bladder sensations,

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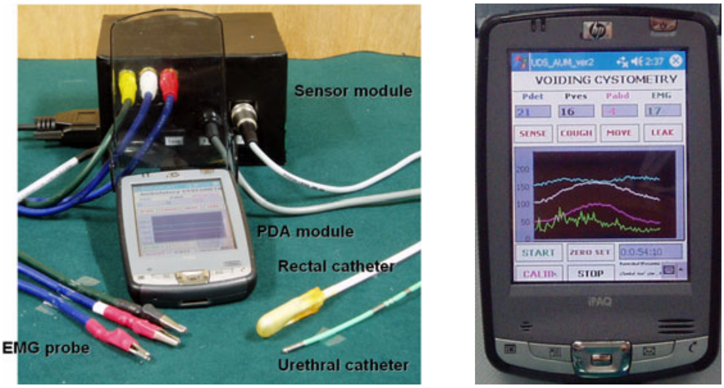
occur to be recorded manually and to allow for the automatic detection of the leakage of urine as well as the fully ambulatory monitoring of the bladder, abdominal and subtracted detrusor pressure. Also, the urodynamics findings obtained using a conventional cystometry device were compared to those obtained using our AUM system.

2 Portable AUM System

The portable AUM system was developed in order to measure the bladder (P_{ves}) and rectal pressure (P_{rect}) by means of catheters, the abdominal pressure (P_{abd}) by means of the EMG signals, described in our previous study [3], and the leakage of urine by means of the impedance changes. A micro-tip pressure transducer urethral catheter monitored both the bladder pressures and leakage of urine, while a rectal catheter monitored the rectal pressures. The sEMG was measured simultaneously using surface electrodes.

First of all, the pressure, impedance and EMG signals were pre-processed by the signal conditioning circuit in the sensor module. It consists of a 60 Hz notch and offset-rejection filter for removing the power noise and offset component of the signals. In addition, a 30 Hz low-pass filter in the two pressure and one impedance channels and 50-250 Hz band-pass filter in the EMG channel were applied to the sensor module, in order to reduce the motion artifact noise due to postural changes and respiration activation. After being conditioned, the signals were digitized by an A/D converter (CF-6004, National Instruments™, U.S.). The sampling rate and resolution of each channel was 500 Hz and 14 bits, respectively. The data were then transferred to flash memory in the control module and displayed on the LCD panel simultaneously. Fig. 1(a) shows the photograph of the catheters, sensor and control module of the constructed AUM device.

In order to analyze and store the data during the study, monitoring software was developed to run in the control module using the LabVIEW PDA module (ver. 7.1, National Instruments™, U.S.). Fig. 1(b) shows the front panel of the developed monitoring software. It can show the trace of the detrusor, bladder, abdominal pressures and EMG signals continuously on a display panel using figures and numbers and simultaneously store the data in flash memory. In voiding cystomerty, the detrusor pressure and volume of the bladder at the time when the subject feels the various bladder sensations, such as first sensation of bladder filling (FSF), first desire to void (FDV) and strong desire to void (SDV) during bladder filling could be quite useful for the diagnosis of the detrusor activity. Accordingly, the system is equipped with event buttons such as 'SENSE', 'COUGH', 'MOVE' and 'LEAK' in order for the time to be marked manually when the specified events, such as the bladder sense, cough, movement and leakage of urine, are observed during the study. The use of these event buttons enable the more reliable diagnosis of the bladder functions, because the clinician can judge whether the changes of the detrusor pressure were induced by the movement artifacts or patho-physiological conditions of the bladder during the filling phase. The 'ZERO SET' button is used for removing the bias of the two pressure signals while the patient's condition is stabilized in the state of the empty bladder. Also, the 'CALIB' button is used for converting the measured sEMG signals to the estimated abdominal pressures. These buttons are manually pressed by the clinician since the patient would be under behavioral restrictions during the catheterization and calibration procedure.



(a) (b)

Fig. 1. Photographs of (a) the developed AUM system and (b) monitoring software

3 Clinical Assessment

The study group consisted of 28 patients (24 males and 4 females) with neurogenic bladders due to spinal cord injury (SCI) who were hospitalized for rehabilitation. All of the patients participated in both the CMG and AUM studies (total 28 CMGs and 28 AUMs). Table 1 represents the demographic and clinical characteristics of the patients. The patients were divided into two groups, the areflexic bladder and detrusor overactivity groups, according to the reflexibility of the neurogenic bladder obtained from the CMG study. The data was excluded from the study if the spike height of the bladder and rectal pressures at coughing was less than 20 cmH_2O or if the quality of the cough signal was poor, viz. grade C [4].

Table 1. Clinical characteristics of the patients

	Areflexic group	Detrusor overactivity group
Sex (male/female)	17 / 2	7 / 2
Age (years)	51.1±13.5	45.7±15.0
BMI	23.2±2.4	23.8±2.7
Lesion(C/T/L)	5 / 7 / 7	3 / 5 / 1

First, the patients underwent a conventional CMG in the supine position according to the standard laboratory procedure in agreement with the ICS recommendations [1, 5]. The bladder was filled with sterile 0.9% saline solution at body temperature with a filling rate of 30 ml/min. A double-lumen fluid-filled catheter (9021P5261, Medtronic™, Denmark) and balloon catheter (9021P4421, Medtronic™, Denmark) were used to measure the bladder and abdominal pressure, respectively. A disposable Ag-AgCl electrode was attached to the left rectus abdominis muscle, and the reference and ground electrodes were positioned near the umbilicus and on the bone above the pit of the stomach, respectively. All of the pressures, EMG signals and times were simultaneously recorded by both the Duet® Urodynamic system (Dantec, Denmark) and our AUM device at a sampling frequency of 500 Hz.

Next, AUM studies were performed with the same patient while they were on the bed of a hospital ward. After free voiding, the patient took a 10 mg Lasix® with 500 ml of water. A micro-tip pressure transducer catheter (9022K0721, Medtronic™, Denmark) was used to record the bladder pressure. A rectal catheter was positioned within the rectum in order to record the rectal pressure. Surface EMG electrodes were attached at the same position as that used for the CMG study.

During the filling phase, the volumes of urine (BV_{FSF}, BV_{FDV}, BV_{SDV}) and detrusor pressures ($P_{det,FSF}$, $P_{det,FDV}$, $P_{det,SDV}$) when the patients felt the bladder sensations FSF, FDV, and SDV, respectively, were measured in both the CMG and AUM studies. The FSF is the feeling when a subject first becomes aware of the filling of the bladder. The FDV is defined as the feeling that would lead the patient to pass urine at the next convenient movement, but where voiding can be delayed if necessary. The SDV is defined as a persistent desire to void without the fear of leakage.

4 Results

Table 2 shows the clinical parameters obtained from the AUM and CMG studies for both the areflexic and detrusor overactivity groups. First, we compared the parameters obtained from the CMG study with those obtained from the AUM study in each group. In the detrusor overactivity group, $P_{det,FSF}$, BV_{SDV} and $P_{det,SDV}$ during AUM were lower than those during CMG ($p<0.05$), and the DO and leakage of urine were more frequently observed in AUM as compared to CMG. In CMG, 19 and 9 patients among the total of 28 patients were diagnosed as having areflexic bladder and detrusor overactivity, respectively. In AUM, 9 (47 %) of the 19 patients classified as having areflexic bladder in CMG were inconsistently diagnosed as having detrusor overactivity, while 1 (11 %) of the 9 patients classified as having detrusor overactivity in CMG was diagnosed as having areflexic bladder. A total of 10 patients (36 %) among all of the patients were classified as having different reflexibility of the bladder in CMG and AUM and, consequently, there was a statistically significant difference between the two studies (McNemar's test, $p<0.05$).

Table 2. Comparison of the clinical parameters obtained from CMG and AUM according to the group

	Areflexic group		Detrusor overactivity group	
	CMG	AUM	CMG	AUM
BV_{FSF}, ml	289.1±106.9	241.0±172.5	207.0±79.4	156.1±78.5
$P_{det,FSF}$, cmH_2O	4.4±4.3	10.7±19.3	16.6± 15.9	5.6±16.3*
BV_{FDV}, ml	372.5±130.5	292.8±148.4	250.4±92.7	238.0±120.7
$P_{det,FDV}$, cmH_2O	8.3±7.5	14.8±22.8	26.1±18.5	16.5±16.6
BV_{SDV}, ml	438.4±118.9	464.5±217.7	325.4±130.4	297.1±153.0*
$P_{det,SDV}$, cmH_2O	10.9±7.1	18.9±20.8	34.9±20.8	16.0±17.4*
BV_{max}, ml	495.5±77.2	484.2±213.8	437.1±94.5	338.9±186.1
Leakage, %	10.5	21.1	44.4	55.6
DO, %	5.3	21.1	44.4	44.4

*: comparison of the parameters obtained from CMGs with those from AUMs in each group, $p<0.05$

5 Conclusion

We developed a fully AUM system and evaluated its clinical utility by applying it to both CMG and AUM studies. Through the clinical assessment, we verified the usefulness and discrimination of the clinical parameters derived from our system, which are used for the evaluation of the bladder function. These results demonstrated that the developed AUM system could be a complementary tool to evaluate various bladder dysfunctions, especially in an AUM study.

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Real-Time Interactive Medical Consultation Using a Pervasive Healthcare Architecture

Bingchuan Yuan and John Herbert

Department of Computer Science, University College Cork, Ireland
{by2,j.herbert}@cs.ucc.ie

Abstract. The phenomenon of an aging society has derived problems such as shortage of medical resources, rising healthcare costs and reduction of quality in healthcare services. Pervasive healthcare aims to alleviate these problems, but many issues remain to be resolved. This paper presents a system called CARA (Context Aware Real-time Assistant) whose design goals are to address these issues in a pervasive long-term healthcare solution. CARA aims to provide efficient healthcare services by adapting the healthcare technology to fit in with normal activities of the elderly and working practices of the caregivers. This system can continuously measure physiological signals, and either store the data on the server or stream the data to a remote location in real-time. A design goal of ubiquitous access has prompted the design of the system as a rich internet application. The only tool required is a web browser with the commonly-available Adobe Flash plug-in installed. Thus the system enables access and analysis on any internet-connected PC or appropriate smart device, independent of geographic location. The remote monitoring and data review applications of CARA are presented at as the main implementation examples. The results of experiments using the system are presented.

Keywords: Pervasive Healthcare, CARA, Data Review, Remote Monitoring, Rich Internet Application.

1 Introduction

While life-expectancy continues to grow, at least in some countries, the inequality in life expectancies and Healthy Life Years (HLYs) [1] remains large. This means that many people live longer but in a state in which chronic conditions substantially affect their quality of life. Furthermore, this inequality has a negative impact on healthcare costs.

One proposed solution to the current crisis is pervasive healthcare [2]. The wide scale deployment of wireless networks will improve communication among patients, physicians, and other healthcare workers as well as enabling the delivery of accurate medical information anytime anywhere, thereby reducing errors and improving access. At the same time, advances in wireless technologies, such as intelligent mobile devices and wearable networks, have made possible a wide range of efficient and powerful medical applications. Pervasive healthcare has the potential to reduce long-term costs and improve quality of service [3-7].

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In this paper we present the CARA pervasive healthcare architecture, with the focus on its web-based real-time remote medical consultation application. The main components of the CARA system are:

1. Wearable Wireless Sensors.
A key component of the system is a BAN (Body Area Network, i.e. a portable electronic device capable of monitoring and communicating patient vital signs), and this includes medical sensors such as the ECG, SpO2, temperature and mobility sensors.

2. Remote Monitoring System.
This is responsible for remotely controlling the BAN and continuously measuring physiological signals of the elderly through the BAN and internet connection. A web camera is integrated to this application that may be used for monitoring and for interaction between the elderly and the caregiver.

3. Data & Video Review System.
This is designed for medical consultant or caregiver to review the data previously collected from the elderly in case s/he might be not available for real-time monitoring. This application not only can present the recorded data in graphic chart but also allows the consultant to view the recorded video of the elderly along with real-time sensor data.

4. Healthcare Reasoning System.
This is implemented by a Windows Workflow Rule Engine, and applies medical rules, appropriate for the individual, to real-time data that is received from the vital sign sensors. A real-time human movement monitoring function has been added in this system which can provide valuable information regarding an individual's degree of physical ability and general level of daily living activities.

2 System Prototype

The current CARA system prototype provides remote physiological signal monitoring with on-demand video recording services, along with a data and video review functionality to assist diagnosis. An overall architecture of the CARA healthcare system is shown in Figure 1.

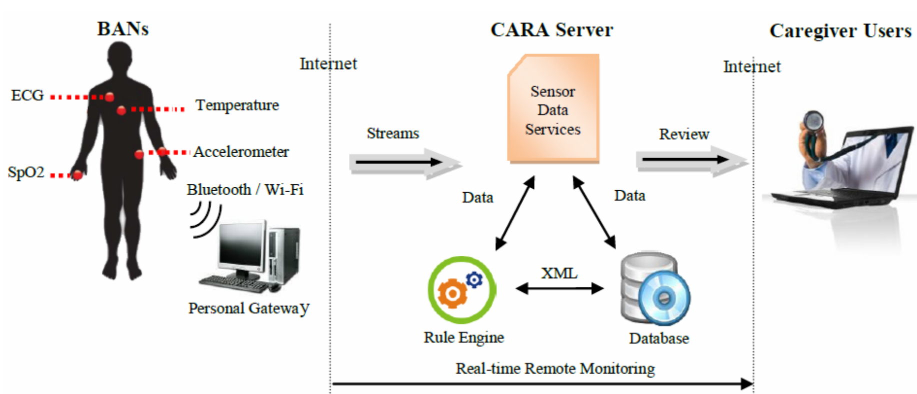

Fig. 1. CARA system architecture

The remote monitoring is able to provide continuous real-time physiological signal monitoring over the internet, and it is also able to send alarms when an emergency is detected. The on-demand video monitoring can be used to provide a live video service in case the caregiver needs more information of the patient. All the sensor readings and video records are stored in the database on the CARA server so that the caregiver can review the data anywhere anytime.

The wireless monitoring devices which are the basis of the body sensor network are developed by the Tyndall Institute of University College Cork. The sensor platform is a generic 25mm×25mm module that has been deployed in applications ranging from medical measurement to agriculture.

3 System Implementation

The CARA system is designed as a web application for physicians to monitor patients remotely. In traditional web applications, there is a limit to the interactivity that can be added to a single page. With RIA (Rich Internet Applications) technologies, the client computer and the server can communicate without page refreshes. This allows the real time user interaction which satisfies an essential requirement of our system. Adobe Flex is one of the latest trends in the realm of Rich Internet Applications. It was chosen for its ubiquity since it is estimated that over 90% of web users now have the Flash Player installed on their computers.

3.1 Real-Time Remote Monitoring System

By using the remote monitoring system, caregivers can monitor patients' biological signals remotely through their web browser (Figure 2). Since the data is transmitted in real-time, a remote consulting physician is able to interact with a patient and observe real-time vital signs. As internet access becomes more readily available, this application becomes a convenient and effective tool for supporting healthcare services.

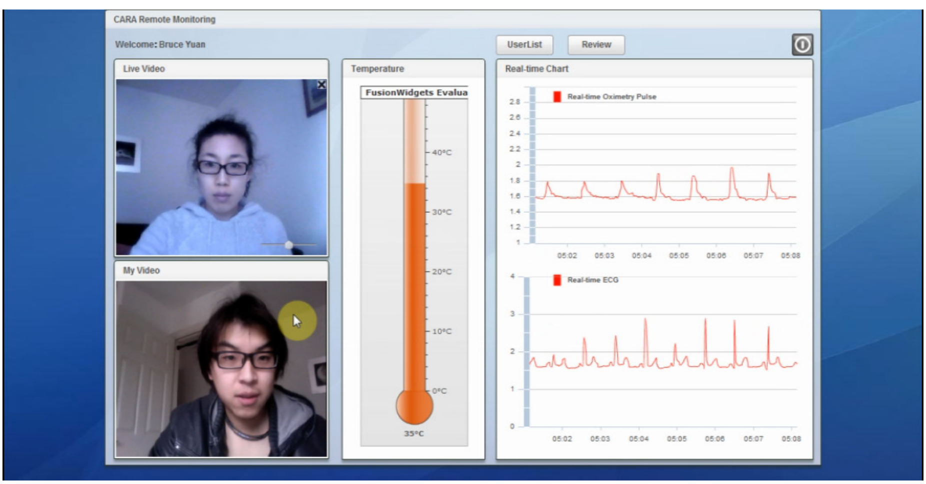

Fig. 2. Remote Monitoring Integrate With Live Video Application

3.2 Data Review System

The data review system includes sensor data review and video replay applications. The sensor data review application allows the caregiver to analyze the full context of the sensor readings for a selected patient within a certain time period in order to distinguish critical from non-critical situations.

The video replay application is designed for the caregiver to review the recorded patient session video along with the associated real-time sensor data. This function is based on the real-time remote monitoring system. Whenever the patient's live video stream is published on the Flash Media Server (FMS), it is also recorded as a flash video file (FLV) on the server. To characterize the video file and to synchronize with the sensor data, several annotations of the video must be recorded into the database as well (e.g. video start time, end time, patient information).

3.3 Healthcare Reasoning System

The Healthcare Reasoning System provides a general rule engine that can be tailored with different rules for different applications (such as for in-clinic assessment or at-home monitoring), and it also executes in real-time and offers immediate notification of critical conditions. Some critical conditions may only be identified from correlating different sensor readings and trends in sensor readings accumulated over time.

The Healthcare Reasoning System is capable of performing three main reasoning tasks: (i) continuous analysis of the vital sign readings in the context of all other available information, (ii) prediction of possibly at-risk situations and (iii) notification of emergency situations indicating a health risk. Raw data coming from sensors is processed by the context management services, producing higher-level information. After this, the rule engine identifies the current state of the patient, following a triage-style model, as (normal, at-risk or emergency). Further analysis in the next step means that if the current inputs (physiological values) are atypical for the patient, an alert output might be upgraded to an emergency. The generated data is stored to assist other decisions and for additional analysis.

4 Non-functional Requirements

Several non-functional/quality requirements are taken into account in the design of the CARA system.

Two experiments were conducted to test the CARA system's physical performance. The first experiment is to evaluate signal quality between the wearable monitoring devices (WMD) and a gateway PC at different distances. We fixed the location of the gateway PC and tested wireless communication link quality at distances ranging from 1m to 15m from the WMD. We found that the closer WMD offered better transmission quality (see Table 1). The signal to noise ratio (SNR) value was also affected by some obstructions such as doors or movement of the subject.

Table 1. SNR Value of the WMD

WMD	**Distance**		
	1m	***7m***	***15m***
SNR(dB)	11	20	33

The second experiment is to evaluate the impact of the potential delay of the network. We tested our remote monitoring system through localhost, intranet and internet respectively, and the results indicating data transmission delay in milliseconds are 50, 200 and 700. The delay caused by internet latency is unavoidable under the current approach. However, this delay does not significantly affect the working of this system.

5 Conclusions

The CARA pervasive healthcare system presented here provides a technical solution for obtaining immediate expert diagnosis when that expert is not around. While it is possible that this service might be available to a patient at home, it is more immediately practicable to use in a remote general practice clinic where the placement of the BAN and use of the equipment may be supervised by a medical attendant. Important aspects of this system include: inter-visibility between patient and caregiver; real-time interactive medical consultation; and replay, review and annotation of the remote consultation by the medical professional. The annotation of significant parts of the multi-modal monitored signals by the medical professional can provide the basis for the automated intelligent analysis of the CARA system. The application was discussed in the context of the overall CARA healthcare architecture, and results of some experiments using the application were presented.

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Hardware Design in Smart Home Applications: Rapid Prototyping and Embedded Systems

Tao Long[1,4] , Johnny Wong[2], Debra Satterfield[3], Hen-I. Yang[2], and Viren Amin[1,4]

[1] Department of Electrical and Computer Engineering,
[2] Department of Computer Science
[3] College of Design
[4] Center for Non-Destructive Evaluation
Iowa State University, Ames, Iowa, 50010 USA
{freeman,wong,hiyang,debra815,vramin}@iastate.edu

Abstract. Research advances in smart home technologies are highly diverse and innovative[1,2,3]. Some of these novel ideas involve in creating new hardware to perform distinct functionality. In this paper, we present two effective methods for transforming these ideas and concepts into actual hardware: rapid prototyping and embedded systems. These two methods used in combination have the benefits of high fidelity, formal documentation (thus can be successively improved), quick turnaround time and low cost. To illustrate these benefits, we demonstrate two prototypes developed in our Smart Home Lab: a physical monitoring and logging device and a smart lamp. Since these two methods are applicable in creating wide varieties of prototypes, our discussion and demonstration should inspire other researchers in smart home areas to use similar methods to create new prototypes and products. To improve overall usability, some design principals and issues are also discussed.

Keywords: Rapid Prototyping, Embedded Systems, Multi-discipline designs, CAD, Usability Studies, Smart Home, Pervasive Computing, Engineering process, Design Process.

1 Introduction

Researches in smart home technologies are highly diverse and innovative. One of the challenges in this area is how novel hardware can be effectively realized. Such step is essential both in testing and deployments[2,3] of novel ideas. Fortunately, modern developments of rapid prototyping tools and embedded systems can be used for such purposes effectively[4]. In this paper, we present these two methods to facilitate the prototyping process in smart home researches. These two methods have the benefits of wide applicability, high fidelity, formal documentation and thus can be successively improved with, quick turnaround time and low cost.

2 Methods

2.1 Rapid Prototyping

As compared to traditionally hand-made processes[9], the use of rapid prototyping tools such as 3D printing, CNC (Computer Numerical Control) machining and laser

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cutting/engraving has the advantages of high fidelity and high repeatability[10, 11].

For smart home prototypes such as actuator parts, sensor casing, typical physical size is generally small[12, 13]. Therefore, the cost of small batch is relative low [11]. Since all rapid prototyping starts with a computer model, potential issues such as manufacturability, clearance, strength and usability can be tested and refined on a software level[11], saving time and cost in actual production. Furthermore, such computer models can be successively refined for better usability.

2.2 Embedded Systems

Applications of embedded systems in home environment are extensive. Typical appliances, such as microwaves, refrigerators and TV obviously have seen such applications. Recent research developments in this area extended such applications even further, such as energy saving thermostat [3, 17], door lock [18] or even humanoid robotics[19]. Thanks to the development of integrated circuits (IC) and microchip technologies, embedded systems on the hardware level are becoming smaller, cheaper and yet more powerful and connected.

As compared to alternative solutions based on interconnecting off-the-shelf product, a well-designed embedded system offer the advantages of compact form factor and higher level of integration among sensors, control and communication. Another advantage is that researchers can make good use of the variety of sensors, ICs and microchip on the market. From a design perspective, such advantages are highly desirable, in that a flexible technical support results in a better prototype design, tailored to enhance human and machine interactions.

3 Examples

Two prototypes are disused below as examples to illustrate these advantages mentioned.

3.1 Life Companion

Life Companion was conceived as a physical well-being monitoring device for independent living senior citizens. It is a wearable device whose primary function is to constantly monitor and record various information such as physical activities detected by an accelerometer, GPS location and temperature and photos. Data recorded in such way can be shared through social networks among family members and health care providers. A secondary function is to relieve symptoms of early Alzheimer's disease by playing back user's location and what the use has seen back to the user. Finally, it can function as a "panic button", which sends out a wireless stress signal through Bluetooth protocol in case of emergency. The receiving end of the stress signal can be PC or a handheld device such as a smart phone. In case of an involuntary fall, the prototype can also send out a stress signal automatically.

With its primary audience being elderly in mind, the primary goals of the design are: physical compactness and operational simplicity. As a result, user interface is reduced to a minimum. The development of this prototype has currently gone through 2 versions. From the first version to the second one, significant changes has been made to reduce its overall size but keep the original functionalities, shown in Fig. 1.

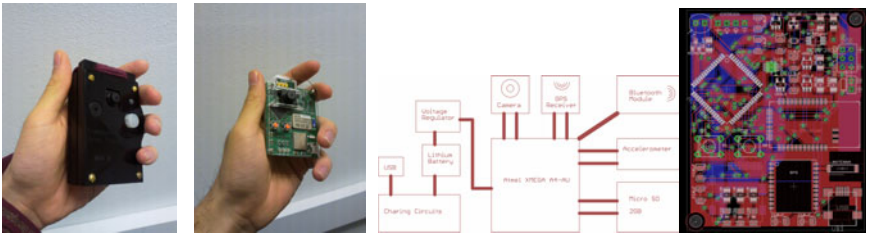

Fig. 1. Left, first version of Life Companion with black acrylic casing; middle left, second version with reduced size and clear acrylic casing showing internal circuit board developed in our study. Middle right, schematic for the second version of prototype Life Companion; right, circuit layout.

Internal Bluetooth module automatically uploads sensor data, GPS location, acceleration and photos to a host computer when the prototype is close enough. To better understand user's physical activity pattern, the prototype should be equipped as much as possible. One reason is that the physical size of the device should be as small as possible.

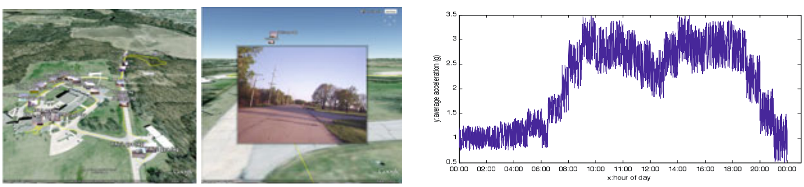

Fig. 2. Left, GPS track (yellow lines) along with photo shown at specific time and location; middle, a close look of a photo captured by life companion, showing the location and orientation of the photo, right, accelerometer data collected in 24 hours period

From a design perspective, the interaction design of Life Companion takes into consideration the social, emotional, and physical conditions of the target audience. Therefore, the shape is meant to work easily for persons with limited grip strength and hand size. It is also designed to be comfortable and appealing to the user. In addition, the brand name, Life Companion, is meant to create a sense of well-being and reinforce the fact that the product should remain close to the person like a friend or companion. These positive brand associations are intended to intuitively indicate how to use the product and how perceive the product in terms of the user's lifestyle.

3.2 Smart Lamp

The other example is Smart Lamp, which can be used for reading and general illumination in a room. Internal sensors include an infrared distance sensor, light sensor, accelerometer and temperature sensor. To turn it on, simply tap anywhere on the lamp and the motion will be registered by the internal accelerometer. When the accelerometer detects the lamp is more or less facing downward, it goes into reading mode and the intensity of the LEDs is determined by the distance between the lamp and the illuminated surface (e.g. book pages) and ambient light level to ensure proper and uniform lighting. Otherwise it goes into general illumination mode, which can be configured to light up only when an ambient light goes below certain level. Furthermore, the multi-color LED array can be configured to output different settings to simulate natural light, such as “sun set”, “natural white”, “artic aurora” and etc. according to user preference through USB. An internal lithium battery can provide emergency power during a power outage. Fig 5 shows the physical appearance of this prototype.

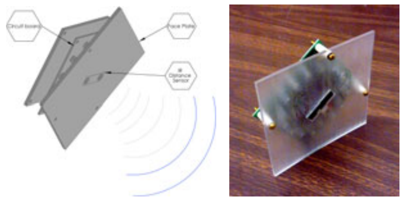

Fig. 3. Left, 3D model (Solidworks 2010) of Prototpye Smart Lamp; right assembled prototype

4 Discussion and Future Works

As demonstrated by these two examples, the applications of rapid prototyping and embedded systems can be effectively used in a variety of smart home applications. To summarize, the combination of these two methods can achieve compact physical size and distinctiveness. The methods described in this paper are suitable for researches in this area to exercise their creativity in coming up new application of smart home technologies[7].

The industry of electronics continues to provide cheaper and better ICs, opening up a wide range of applications. Like many other technologies, it is a multidiscipline area, where engineering, design and even architecture must be incorporated. While the technologies opens up wide possibilities, these possibilities have to be constrained by usability and user-friendliness. We hope some of the techniques discussed in this paper will help transform novel ideas into actual prototypes.

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Audiovisual Assistance for the Elderly - An Overview of the FEARLESS Project*

Rainer Planinc, Martin Kampel, and Sebastian Zambanini

Vienna University of Technology, Computer Vision Lab,
Favoritenstr. 9/183-2, A-1040 Vienna, Austria
{rplaninc,kampel,zamba}@caa.tuwien.ac.at
http://www.caa.tuwien.ac.at/cvl

Abstract. This paper gives an overview of the recently granted AAL-JP project FEARLESS which stands for "Fear Elimination As Resolution for Loosing Elderly's Substantial Sorrows". The proposed project aims to reduce elderly's fears within their homes. As elderly potentially refuse or forget to wear any additional sensors to activate alarm calls, FEARLESS will visually and acoustically detect and handle risks by contacting the relatives or care taker organization automatically - without the need of any user intervention. This is done by using only one single type of sensor making the system affordable for everyone. It increases the feeling of safety, reduces fears, enhances the self-efficacy and thus enables elderly to be more active, independent and mobile in today's self-serve society.

Keywords: ambient assisted living, automatic risk detection, elderly.

1 Introduction

Emergency systems for elderly contain at least one sensor (button or accelerometer) which has to be worn or pressed in case of emergency. These emergency call buttons are provided by care taker organizations having the main drawback that no information about an occurred incident prior the button is pressed is available. Moreover, people have to wear these buttons which they tend to forget or even refuse. In case of an emergency and if elderly are able to press the button, they have to tell the operator which kind of incident happened. If the elderly is not able to talk to the operator for any reason, there is no information about the type of incident. This causes false alarms as well as ambulance deployments, although there is no emergency situation at all. To ensure the detection of emergency situations where the elderly is not able to actively raise an alarm (e.g. due to the lost of consciousness), sensors acting autonomously are needed.

Autonomously acting sensors are used in the field of smart homes to fulfill core functions defined in [6]: the control of the system, emergency help, water and energy monitoring, automatic lighting, door surveillance, cooker safety, etc.. Due to various reasons summarized in [2], smart homes are not established yet.

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One of the reasons mentioned in [2] are the costs: it is easier and less expensive to integrate smart home technology into new buildings than it is for already existing buildings. This results in the demand of a robust system, which can be integrated into existing buildings. Moreover, one of the outcome of the former project MuBisA [17] is that elderly accept technical assistance only if the system is not discernible for third persons (i.e. visitors).

Considering these facts, a computer vision approach is feasible as it is able to overcome the limitations of other sensor types [11]. Furthermore, not only falls can be detected but also other events where help is needed (e.g. fire, flooding,...). By the use of a vision based system the detection of emergency situations is done by software, meaning that this system is extendable as only the respective algorithms need to be developed or adopted. A wide variety of computer vision algorithms for different applications exist (e.g. [3,4,14,15]), but there is no "perfect" algorithm for detecting emergencies in elderly's homes yet.

As falls are considered to be a major risk for elderly, there has been done research on automatic fall detection [12]. Not only the fall itself but also the consequences of a fall are a great risk for elderly. Noury et al. [13] have shown that getting help quickly after a fall reduces the risk of death by over 80% and the risk of hospilization by 26%. Hence, FEARLESS is able to provide emergency service – if needed – immediately.

2 Event Detection

The goal of this project is to detect a wide range of risks with a single sensor unit, enhancing mobility and enabling elderly to take active part in the self-serve society by reducing their fears. In order to detect reduced mobility, a long-term tracking of the elderly is considered in the FEARLESS system. Another main focus of this project is the lack of expertise at the supplier side and thus the integration of important parts of the supply chain (i.e. network of electricians and electric shops). To ensure a holistic approach, the project consortium does not only consist of technical members, but also of psychologists, medical scientists and companies being able to transfer the knowledge from research to economy. Furthermore, the integration of end-user organizations ensures that end-user's wishes and needs are considered throughout the whole project.

The FEARLESS system uses cameras equipped with microphones as sensors, allowing for the combined visual and acoustic detection of risks. Furthermore, we make use of a late fusion approach developed during the former project MuBisA, performing analysis of the scene on each camera individually and then combining the individual results to get an overall decision [18], as shown in Figure 1. In contrast to other works (e.g. [1]), our system is not vulnerable to low-quality images, as only some basic information (e.g. silhouettes) are extracted from the image. We define empirical, semantic driven rules using features with fuzzy boundaries introduced in [5] to analyze the scene and make the decisions.

To be able to visually detect risks, the following steps are applied:

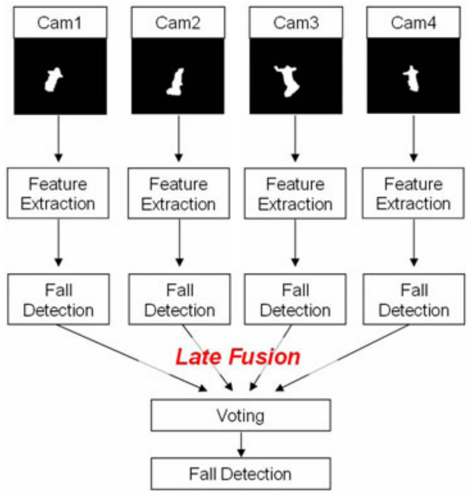

Fig. 1. Late Fusion for multi-camera fall detection [18]

1. **Motion detection:** First, motion detection is performed on the video to segment motion (e.g. the person) from the background. For this purpose, a robust background model has to be established which is able to adapt to changing conditions (e.g. lighting) as well as to reject motion in the background (e.g. a TV). A recently upcoming promising concept for background modeling is boosting [8] which permits the rejection of recurrent motion in the background during run-time without any presumptions. To increase robustness, color information is also exploited for shadow detection [9].
2. **Feature identification:** According to the different risks to be detected, a collection of various features is extracted. Fall detection requires features describing the human posture [4]. Specific actions can be detected by the use of space-time interest points [10]. Other events like smoke can be detected e.g. by using a wavelet transformation or dynamic texture change as feature. A dataset for evaluation of features is provided by [16].
3. **Risk detection:** Different risks (e.g. fall, fire, flooding,) are pre-defined to interpret the features and relate them to the risks by using confidence values. The final decision about the current risk for a single camera is made by a voting step which combines the individual confidences. By the use of multiple cameras, the overall robustness and reliability of the system is increased since the voting neglects individual wrong detections. Moreover, the problem of occlusions (e.g. by furniture) is implicitly solved.

To overcome the limitations of computer vision approaches, in the FEARLESS system risk detection also comprises the processing of audio data from microphones. This allows for combined audiovisual data processing, which is based not only on visual information but on the accompanying audio signal, and enhances the general performance of the risk detection. Due the smaller size and dimensionality, audio data is easier and faster to process than video data. Many of the events to be detected by the FEARLESS system are usually accompanied by characteristic audio sounds that could provide useful information for detection, e.g. the loud sound when accidentally falling on the floor followed by silence. Audio classification is a major application area of pattern recognition, i.e. the scientific discipline whose goal is the automatic classification of data patterns into a number of categories. A multi-stage approach is performed to recognize events from audio data, consisting of the following steps:

1. **Silence elimination:** audio is checked first for a processable signal, in order to prevent a further processing of audio containing silence only. This is achieved by comparing the audio power against a threshold value estimated from a long-term analysis for each microphone.
2. **Feature extraction:** audio signals can be represented in the time domain (time-amplitude representation) or the frequency domain (frequency-magnitude representation). Common features used are the average energy, zero crossing rate or silence ratio in the time domain, and bandwidth, energy distribution or harmonicity in the frequency domain.
3. **Audio pre-classification:** the audio data is classified into some common types of audio such as speech, sounds or noise. This is achieved by either using each feature individually in different classification steps or by using a set of features together as a vector to calculate the closeness of the input to the training sets.
4. **Final audio classification:** based on the output of the previous step, the different audio types are further processed in different ways. For speech recognition, techniques based on Hidden Markov Models [7] are applied as they are currently the most widely used and produce the best recognition performance. For sound recognition, Dynamic Time Warping and Artificial Neural Networks have shown promising results in the past.

3 Conclusion

In this paper an overview of the FEARLESS project was given. Due to elderly's reluctance or forgetfulness to wear any devices, the FEARLESS project is designed to detect different events using audiovisual pattern recognition algorithms automatically. By providing safety, elderly will suffer from less fears and thus being more active in todays self-serve society. To ensure a holistic view, the project consortium consists of partners from different disciplines and thus not only technical aspects are covered. Finally, the integration of the supply chain and also elderly throughout the project is crucial. At a later stage of the project, field tests and pilot phases will be conducted to validate this approach.

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Wrenching: Transient Migration from Commonality to Variability in Product Line Engineering of Smart Homes

Sugam Sharma, Hen-I. Yang, Johnny Wong, and Carl K Chang

Department of Computer Science, Iowa State University, Ames, Iowa, 50010 USA
{sugamsha,hiyang,wong,chang}@iastate.edu

Abstract. Currently smart home are created and deployed on each user's specifications, which guarantees their complete satisfaction, but incurs a very high deployment cost and non-usable resources. Techniques from product line engineering provide a framework to promote resource reusability by identifying reusable common features. They help to reduce the cost but can compromise users' satisfaction, especially when they need special accommodations or have unique preferences. In this paper, we propose wrenching, a transient relaxation of common features into variability, so uncommon, ad hoc request can be satisfied. Based on wrenching, we further devise Smart Variability Model, that can accommodate situations where existing models are not applicable.

Keywords: Smart Home, Customization, Deployment, Product Line Engineering, Wrenching, Commonality, Variability, Smart Variability Model.

1 Introduction

Currently in commission based smart home deployment, the smart home vendor consults with the individual resident about the facilities needed in the home and gathers the requirements. Based on the requirements, vendor implements the appliances inside the home and embeds the smart devises with appropriate technology to operate them. Though this makes the inhabitant satisfied but incurs very high cost and the resources once used in a home cannot be reused. In this paper we address these issues - cost and non-reusability - by introducing the Product Line Engineering (PLE) [1] concepts in smart home deployment, keeping the same objective – each individual resident's satisfaction – as the top priority. In a traditional PLE, a domain [1] consists of a set of common features (functional and non-functional) – also called commonality and a set of variable features - variability. The common features, also known as core assets [1] are bound with each application and PLE reuses the core assets in application development. The inclusion of variable features heavily relies on the customer's profile and are bound for a specific application only. The reusability of core assets helps in cost reduction of application development. Economy of scale [2] is always a concern in PLE and is attained, especially by enhancing the degree of commonality, resulting in compromise with few customers' satisfaction sometimes.

A traditional PLE approach cannot be directly applied in smart home deployment as it does not satisfy each individual customer. In a smart home [3] system the primary

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goal is to provide assistance to senior citizens to live independently. A senior resident may have various functional disabilities and imposes constraints on few common features on the deployment of the smart home. The constrained common feature is either replaced by another suitable/ desired feature (may be external) or removed completely at deployment time without disrupting the original domain structure. This results in ad hoc variability in commonality, not known in advance during domain analysis i.e. a feature is migrated transiently from commonality to variability till the current deployment request is satisfied. In this paper this transient migration of a feature from commonality into variability is called wrenching.

In PLE, Feature Model (FM) and Orthogonal Variability Model (OVM) [4] are considered as the most popular and widely accepted variability management techniques proposed in literature. They model commonality and variability efficiently but fail in case of wrenching. This motivates us to devise a new modeling technique, called Smart Variability Model (SVM). This is able to cater not only the existing commonality, and variability of a domain but also the ad hoc variability.

Though wrenching process is straight forward but can become complex when there are dependencies, e.g. a feature in commonality to be wrenched, has dependency on other features or vice-versa. We do not address these dependency issues in this paper.

The rest of the paper is organized as follows. Section 2 describes the smart home system. Section 3 and 4 describe existing and proposed approaches for smart home deployment, and their costs and benefits respectively. Section 5 concludes the paper.

2 Smart Home System

Commonality and variability perspective. In this paper we consider a smart home at Iowa State, a result of interdisciplinary research aiming to help elderly, and constituted by various modules (features) - a few of them are classified in table 1.

Table 1. Module classification

Common	Variable
TV/DVD	Food
Smart Fridge	Talk
Smart Microwave	
Security Camera	
MISS(Google Health)	
User Interface	

Limitations perspective. Senior residents may impose numerous potential limitations on the deployment of smart home such as a *Non-English speaking resident,* has motor impairment - unable to use *User Interface*(*TGBI,* please refer fig.1 in section 3.2) - but has no speech impairment. She/he speaks well in native language but not in English.

3 Smart Home Deployment

3.1 Current State of Art

Today, smart home deployment is based on commissions and based on the individual inhabitant consultation, the vendor implements the needed appliances and embeds the smart devises in home. This guarantees inhabitant's satisfaction but incurs heavy cost as everything gets restarted from scratch and nothing could be reused from previous deployments. We see the possibility of feature reusability from the previous applications by applying PLE concepts in smart home deployment.

3.2 Existing Product Line Approach

We present two most popular and widely accepted variability models below:

Feature Model (FM) [1]. The commonality and variability of a product are demonstrated by a feature tree, comprising a hierarchical decomposition of features. Fig. 1 is the FM of smart home described above.

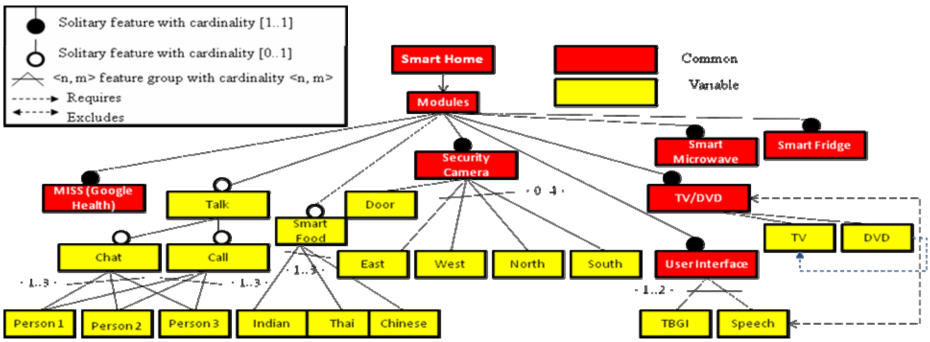

Fig. 1. Feature Model of smart home

Orthogonal Variability Model. Unlike FM, OVM considers only the variable aspects of a product line and captures variability only in design and avoids common features. The principle constraint that OVM imposes on variation point is to provide at least one variant. It is easy to drive equivalent OVM from FM [5].

A traditional PLE approach guarantees feature reusability, and economy of scale but to achieve each customer satisfaction, it cannot directly be applied to smart home deployment. Because of the severe impairments, a senior resident may impose lots of constraints on few common features to be used in smart home deployment. We propose a new technique to achieve each customer satisfaction in PLE.

3.3 Wrenching – The Transient Migration

In a traditional PLE a vendor targets a large pool of customers with the objective to maximize the profit rather each customer satisfaction and adopt vendor initiated top - down approach in product deployment. As stated earlier in smart home we target smaller pool of customers comparatively where each inhabitant's satisfaction is the prime objective. Smart home deployment follows customer-initiated bottom-up approach where product is customized first per-resident basis. So a traditional PLE cannot be used in this case. There are situations when a senior resident in smart home imposes potential constraints on using a common feature. We resolve this issue by temporarily replacing the constrained common feature by the needed feature at deployment time, without redesigning the original domain. Thus a sudden (ad hoc) variability occurs in commonality, not known in advance during domain analysis. This means a common feature is transiently migrated (fig. 2) into variability and this process of transient migration is known as wrenching. The existing variability models e.g. FM, OVM are unable to model ad hoc variability. This motivates us to devise a new variability model which not only caters existing commonality and variability but ad hoc variability also. We call it Smart Variability Model.

Smart Variability Model (SVM). Unlike the existing variability management models e.g. FM and OVM that model only exiting commonality (C_E) and variability (V_E), SVM handles adverse situations also, resulting in ad hoc variability ($V_{ad\ hoc}$).

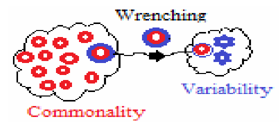

Fig. 2. Wrenching process

Definition 1. ***Commonality*** is a set of functional and non-functional features to be bound with each product of a domain in PLE.
Assume that *pl* is a product line, *p* is a product, and *c* is a functional or non-functional feature; $F = \{c \mid c \in p,\ \exists\, p \in pl\}$ is the set of all features of any product *p* belongs to the product line *pl;* then $C_E = \{ c \mid c_i \in p,\ \forall p \in pl,\ c_i \in F\}$ is known as *commonality* and c_i is a *common feature.*

Definition 2. ***Variability-*** In a system, a variation point is the location where variation occurs. There may be a few choices available to fill the location. These choices are called variants. In order to create an application, a variant is selected, from the set of variants for each variation point. In a PLE- ***variability*** is a set of such variants.
Assume v_r*:* any variant where $r = \{1 \ldots m\}$ *and* $v_r \subseteq F$*;* vp_k*:* any place in a system where variation occurs - variation point, where $k=\{1 \ldots t\}$ and $v_r \models vp_k$, then $V_E = \{ \forall v_r \}$ is ***variability.***

Definition 3. ***Wrenching*** is a customer request's initiated and customer specific process that transiently migrates few features from *commonality* into *variability* at the deployment time due to potential limitations of a senior citizen. This generates *ad hoc variability* in *commonality*, meaning that optional variation point(s) are created at that location.

Algorithm: Pseudocode for Variability Management using Smart Variability Model.

```
1:  List cE ←Commonality, List vE ←Variability
2:  List vpT, vT, vpN , vN , limits ←null
3:  List vpE ←List of existing variation points, String p ←User's profile
4:    Check for restriction on common features
5:     limits ← Restrictions on items in cE imposed by p
6:      For each limit in limits
7:       If (limit == true)
8:         vT ← ad hoc variability derived from cE due to limit
9:         vN ←vT + vE
10:        vpT ← variation points occurred in cE
11:        vpN ← vpT + vpE
12:         For each vp' in vpN
13:          select the required variants from vNT
14:          bind variants from vN to vp'
15:        bind remaining commonality from cE
16:      Else
17:        bind the commonality from cE
18:         For each vp in vpE
19:          select the required variants from vE
20:          bind the selected variants to vp
```

Let *Q* be a request from a customer, for a product *p:* $\forall p \in pl$ where *pl* is any product line. *Q* imposes any constraint *l* on c_i feature of the commonality to be bound such that ; $Q: l \mapsto c_i : C_{NT} = C_E - c_i$ then $\exists\, k+1^{th}$ variation point, vp_{k+1} *; if* $c_i \in V_{adhoc}$ and $V_{adhoc} \in p$, V_{adhoc} is called *ad hoc variability :* $V_{NT} = V_E + V_{ad\ hoc}$. C_{NT}, *and* V_{NT} are new transient *commonality* and *variability* respectively. Assuming $\exists\, v_e, \subseteq F$, any external variant that can satisfy user's limitation. $\Rightarrow v_e \models vp_{k+1}$, if v_e available; otherwise remove vp_{k+1} itself.

Algorithm. C_E – Existing commonality; V_E, V_T, V_N – Existing, Temporary, New variability; VP_E, VP_T, VP_N – Exiting, Temporary, New variation points. This algorithm manages the commonality, if a user's profile imposes any limitation on common feature (s) (line 4). The rest of the algorithm is self-exploratory.

Case Study. SVM models limitation scenario (section 2) - to replace English language specific speech interface, common feature with relevant speech interface – resulting in ad hoc variability in commonality itself - fig.3 (dark circle with slant lines). Rest of the fig. 3 is same as fig. 1.

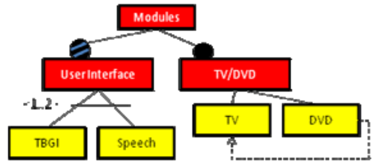

Fig. 3. Adhoc variability in smart home

4 Cost – Benefits Analysis

We use a first order cost model for PLE: $Cost_n = C_{cab} + \sum_{i=1}^{n}(C_{unique}(p_i) + C_{reuse}(p_i))$; C_{prod} – cost of building a module (lets assume x =1 for simplicity) [6]. C_{unique} (development cost of product-specific) = 30% × C_{prod} (per feature); C_{reuse} (reuse cost of PL artifacts) = 10% × C_{prod} (per feature); C_{cab} (investment into PL infrastructure (core asset base)) = 150% × C_{prod} + $C_{scoping}$; For simplicity $C_{scoping}$ (scope definition cost of feature) = 0; n - number of products in PLE and two different sizes (say n=3, 200) of product line are used for cost analysis.

- **Current Common Practice (CCP) –**The cost function has following values. C_{reuse} = 0; C_{unique}= 1; C_{cab} = 0; $N_{Total\ modules}$ = 8; then $Cost_3$ = 24; $Cost_{200}$ = 1600;
- **Product Line Engineering Applied (PLE)-** Assume two optional modules. $N_{coremodule}$ =6, $N_{variablemodule}$= 2; C_{reuse}=.1;C_{unique}=.3;C_{cab}=1.50; then $Cost_3$=5.1;$Cost_{200}$= 241.5;
- **Wrenching Process (WREN)-**Assuming one feature got wrenched. C_{reuse} = .1 ; C_{unique}= .3; C_{cab} = 1.50; $N_{core\ module}$ = 5, $N_{variable\ module}$= 3, $Cost_3$= 5.7; $Cost_{200}$= 281.5

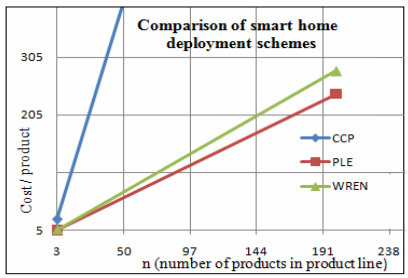

Fig. 4. Per product cost demonstration

Fig. 4 demonstrates that PLE enhances economy of scale. In WREN, wrenching of one feature raises the cost by 14.2% compared to PLE and reduces that to 82.5% compared to CCP, guarantying customer satisfaction in every case.

5 Conclusion

The current state of art of smart home deployment and exploitation of PLE concepts both have trade-off between cost and customer's satisfaction. To achieve better tuning trade-off, we proposed the transient migration of feature(s) from commonality to variability at deployment time and this temporarily drifting of features was called wrenching. We devised Smart Variability Model (SVM), which models ad hoc variability also. We employed the first order cost model to elect the efficient approach and conclude WREN is a better choice that guarantees customer satisfaction with little higher cost then PLE.

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An Intelligent Agent for Determining Home Occupancy Using Power Monitors and Light Sensors

Stephen Makonin and Fred Popowich

Simon Fraser University
School of Computing Science
{smakonin,popowich}@sfu.ca
http://www.cs.sfu.ca/

Abstract. Smart homes of the future will have a number of different types of sensors. What types of sensors and how they will be used depends on the behaviour needed from the smart home. Using the sensors to automatically determine if a home is occupied can lead to a wide range of benefits. For example, it could trigger a change in the thermostat setting to save money, or even a change in security monitoring systems. Our prototype *Home Occupancy Agent* (HOA), which we present in this paper, uses a rule based system that monitors power consumption from meters and ambient light sensor readings in order to determine occupancy.

Keywords: Smart Homes, Intelligent Agents, Occupancy Detection, Power Consumption, Ambient Light Sensors, Energy Conservation, Sustainability.

1 Introduction

Research into *intelligent homes* has focused on a range of different issues, including *human-home* interaction [6], and occupant safety [10]. There remain some very basic issues, though, that play a key role to a wide range of smart home investigations [12,11,4,5]. One of these basic issues is *how to detect if someone is at home*. The automatic determination of whether someone is home can be difficult, but has a number of exploitable benefits in terms of energy conservation, sustainability, and cost savings for the homeowner. Consider an intelligent agent (IA) that could turn down the heat by 2°C when no one is home. Such automatic behaviour could save the home owner money by lowering heating costs and could also save the home owner time, since (s)he would not need to (remember to) override the thermostat setting.

In general terms, the different factors we can monitor are: *consumption* (C) of power from appliances or devices; *environmental* (E) sources such as temperature, light levels, time/date, noise; and the *movement* (M) of individuals, and even air. All three of these factors are significant to determine home occupancy or activity patterns, but for our current study, we are only looking at the first two in any detail.

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Home Occupancy Agent (HOA) is our first single agent system prototype for a smart home. In this paper, we explore how different types of sensors can enable HOA to determine whether a home is occupied or unoccupied. We adopt a *bottom-up* approach; looking at each type of sensor in detail, first. In section 2 we introduce our centralized intelligent agent design. We then discuss the ideas behind monitoring power consumption (in section 3), and investigate ambient light sensors (in section 4). We introduce a *profile matrix* and discuss how to use it in conjunction with ambient light sensor readings to better determine household and room activity. In section 5, we describe our implementation of HOA in a *real home* using *off the shelf products* and report on our test results. We relate our research to similar studies in section 6, and provide some conclusions and directions for future research in section 7.

2 Intelligent Agent Design

Types of agents that will run in a smart home can be categorized as either centralized or localized agents. Moslehi notes that there is a *virtual hierarchy* and a *temporal dimension* to any agent system that needs to be developed for the smart grid [8,9]. Both the smart home and the smart grid are similar in this way; they have a centralized server system, and localized controls and sensors.

Centralized agents will have a responsibility to collect and store localized sensor data on a continual, periodic basis. These agents can then report aggregations of this data and present them to the user either via the web or an in-home display (IHD). Whereas, *localized agents* monitor the sensory equipment directly connected to them and make localized intelligent decisions based on the data from the sensors they monitor. Agents will need to communicate with other agents within the home through a series of events, triggers, parameters, and alarms [8]. Note that we are proposing an agent that focuses on a more centralized approach. That is to say the agent will be running on a server and accessing data collected from local sensors via a database to make decisions. We do this to simplify our initial investigation. Another simplification for our initial implementation is that HOA will be a *rule-based* intelligent agent.

3 Power Consumption

When monitoring electric power consumption (C^E) for detecting occupant activity we look for spikes in kilowatt (kW) readings that correlate directly with occupants turning appliances on and off. Monitoring power consumption will be an ideal choice in the future due to high priority initiatives from electric utility companies who will be installing *smart meters* on every home (meaning data will be available to use and study).

It is useful to meter non-occupant triggered equipment such as heat pumps to get a more accurate activity determination and find a baseline kW reading for the home, called *rest of house* (C^E_R). Any spike above some *safe margin* (C^E_M) would be then considered occupant triggered activity. For example, our test home had a $C^E_M = 0.9$kW because the ambient consumption of the house (C^E_R) oscillated anywhere from 0.2kW to 0.7kW (due to fridges, freezers, electronics on stand-by mode). From the above observations we can derive the following formulae:

$$C^E_A = C^E_{A1} + C^E_{A2} + \cdots + C^E_{Aa} . \tag{1}$$

$$C^E_R = C^E_T - C^E_A . \tag{2}$$

$$activity? = \begin{cases} true, & \text{if } C^E_R \geqslant C^E_M . \\ false, & \text{otherwise} . \end{cases} \tag{3}$$

In (1)-(3), C^E_T is the kW reading of the *whole house*, C^E_{A1} to C^E_{Aa} is a set of kW readings from occupant independent consumption activities (or appliances) that we want to filter out, and a is the number of filtered out activities (or appliances).

4 Ambient Light Sensors

When monitoring ambient light (E^L) sensors for detecting occupancy we look for illuminance spikes measured in lux (lx). By placing ambient light sensors in various rooms, these spikes can correlate directly with occupants turning lights on and off in different rooms. For example, from the data collected in our test home, we observed that light levels were dramatically different in each room.

A room's light levels lack *smoothness* that can be attributed to sunlight levels changing from clouds (not occupant activity) or open and shut blinds (a sign of occupant activity). A *profile matrix* becomes part of the solution because any lux spike may or may not be considered occupant activity. For example, a lux spike in a dark north facing room during the day would be activity but that same spike in a bright south facing room would not.

$$activity(n)? = \begin{cases} true, & \text{if } E^L_n \geqslant PM(n,p) . \\ false, & \text{otherwise} . \end{cases} \tag{4}$$

In (4), let PM be the 2D *profile matrix* indexed by *sensor position* (n), and the *day period* (p), E^L_n be the lux reading from the ambient light sensor at n.

5 Experimentation Setup and Evaluation

We implemented HOA in a *real home* using *off the shelf products*. Ambient light sensor and power meter data were collected over a ZigBee home area network (HAN) at 15 minute intervals. Weather [1] and day period [2] data sets were retrieved from external third party websites. We collected data from January 22 to August 28 (2010) for a home in Burnaby, Canada. HOA analyzed the historical data looking to see if anyone was home or not. Results from HOA were then compared to the expected/correct results (what actually happened) using the standard precision-recall methods.

Determining occupancy by **power consumption** yielded an **f-score of 1.000** (precision score of 1.000, recall score of 1.000). This accuracy is not surprising, particularly if you are able to cancel out background consumption from known non-occupant triggered events as the threshold value in equation (3).

Determining occupancy by **ambient light sensors** yielded an **f-score of 0.943** (precision score of 0.926, recall score of 0.962). This did work very well. A more detailed examination found there were 19 out of 219 days where the day's precision or recall scores were below 80% due to unusual light levels and sensors not being optimally placed (a limitation due to the design of the sensor).

6 Related Work

Current research revolves around identifying what the occupant is doing. PlaceLab [11,6] and MavHome [4,5] both use sensors as a commodity. We are interested in a slightly different approach. We want to use the least amount of sensors at the lease cost possible to determine occupancy. Since each sensor consumes energy, it would *not* be beneficial if the cost of running a smart home system was more than the amount of savings the system could realize. We fully agree with MavHome's objective to *minimize operation cost* [5].

We feel the use of real homes is important in evaluating the performance of IA systems (as does PlaceLab [11,6]). Sensors should be ubiquitous. We do not see wearable sensors (like RFID gloves [10]) as part of the solution. Currently, wearable sensor technology is cumbersome and not practical. Wilson *et al* [12] discuss why wearable sensors are not appropriate for people with disabilities. Cameras and microphones as sensors have also been used in PlaceLab [6]. We feel that these types of sensors are too costly and too intrusive as Abascal [3] has pointed out.

Ambient light sensors in a home are susceptible to small changes in lighting levels. Mohamaddoust *et al*'s system only acted on changes of 50lx [7]. This is far greater than the level we have observed in our test home where light sources can change by as little as 3lx. Light from the sun and atmospheric changes had a dramatic effect on our ability to evaluate light levels, and is an important factor to consider. Mohamaddoust *et al* state the same for their LACS specifications but later on when testing do not consider these scenarios [7]. This again stresses the importance of testing research in a real home.

7 Conclusions and Future Work

With our key constraint of using a minimal number of inexpensive sensors, we were able to use power consumption and ambient light senors to accurately detect home occupancy. Seasonal effects (e.g. summer, winter) and environment effects (e.g. light bulbs burning out thus changing light levels) can have performance impacts on the correctness of determining occupant activity. Identifying the *weak spots* of each the type of sensor is critical in identifying what different complementary sensors are needed to be deployed in future research.

There are many directions that we can take HOA. A high priority item for us is to incorporate a *learning-based* algorithm to complement our *rule-based* ones. Adding more intelligence presents opportunities to explore *Reenforcement Learning*, and *multi-agent systems* or distributed intelligence. We feel that ultimately it would be better if more than one sensor could be used to determine occupancy activity as a way to confirm that the activity is truly from the occupant. For example, a power spike in the kitchen could be confirmed as activity because the motion sensor was triggered as the occupant moved.

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Robotic Computer as a Mediator in Smart Environments

Hyun Kim, Young-Ho Suh, Joo-Haeng Lee, Joonmyun Cho, Moohun Lee, Jeongnam Yeom, Blagovest Vladimirov, Hyoung Sun Kim, and Nam-Shik Park

Network Robot Research Team, ETRI
Daejeon, Korea
{hyunkim,yhsuh,joohaeng,jmcho,leemh,yeomjn, vladimirov,kimhs,nspark}@etri.re.kr

Abstract. With the advance of IT technologies, a new type of computing device will be introduced for smart environments in the near future. In this paper, we outline our on-going development of the robotic computer that naturally interacts with users, understands the current situation of users and environments, and proactively provides users with services. The proposed robotic computer consists of a control unit and an agent unit. The control unit, which is a remote processing server connected to the host server of the smart environment, provides memory (high-level information) and processing (computing resources) capabilities to the agent unit. The agent unit is a portable device which is wirelessly connected to the control unit, and interacts with users and physical objects. We describe the system architecture and the implementation of a proof-of-concept prototype of the proposed robotic computer.

Keywords: robotic computer; service robots; smart environment; multi-modal interaction; situation-awareness; proactive service agent.

1 Introduction

ETRI has carried out the project on the development of a new type of computing device aiming to be realized in smart environments. The main goal of the project is to propose the concept of a new type of computer and develop the working prototype that will demonstrate the three feature technologies as follows: First, it provides more natural and comfort user interactions based on multi-modal interfaces under the robotic spatial augmented reality environment using two pairs of camera-projector, a microphone array and touch sensors. Second, it manages and keeps tracks of the current context acquired from networked resources in the smart environment as well as its own, and adapts its interaction at runtime. Finally, it progressively revises its interaction by learning the user preference model from user's feedback, and proactively provides appropriate services.

In this paper, we outline the system architecture including HW configuration and SW modules, and also discuss the system implementation of a proof-of-concept prototype.

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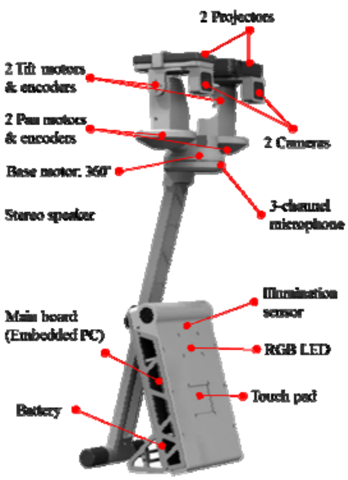
2 System Description

The robotic computer consists of a control unit and an agent unit. The control unit is a remote processing server which provides more computation resources and environment information for the agent unit. It can be connected to smart environments with a flexible manner based on its underlying software architecture. The agent unit is a client-side robotic device which is equipped with various types of sensors, is wirelessly connected to the control unit, and interacts with users and physical objects.

2.1 Hardware Configuration of Agent Unit

Table 1 shows HW specifications for the prototype implementation of the agent unit.



Hardware components	Specifications
(1) Main control board	(Contron) COM Express Embedded System - CPU: Intel ATOM processor X530 - RAM: DDR2 1 GB - Graphic: Intel GMA 500, 2 RGB output - OS: Windows XP Embedded
(2) Peripheral device control board	Customized Embedded Board - Cortex M3 Controller - ADCs for Sensors (Illumination Sensor etc.) - 3x4 Touch Sensors - 24 RGB LEDs
(3) Projectors	(Optima) PK201 Pocket Projector - Resolution: Native WVGA(854x480) - Brightness: 650 ANSI lumens - Light Source: RGB LED
(4) Cameras	(Microsoft) LifeCam HD-5000 - 16:9 widescreen, 720 (1280x720) capture - Auto Focus
(5) Actuators	(Robotis) Dynamixel DX-117 - Running Degree: 0 ~ 300 deg. - Resolution: 0.29 deg. - Stall Torque: 15kgf.cm(12.0V, 1.4A)
(6) Microphone	Customized Sampler - 3 x Electret Condenser Microphone (ECMs) - Sampling frequency: 8KHz ~ 44.1KHz - 16-bit resolution

Fig. 1. The hardware configuration of the prototype of an agent unit

It has two cameras, two projectors, a 3-channel microphone array, a stereo speaker, 3x4 touch sensors, an illumination sensor, a full-color LED and an embedded PC with wireless networking. It has 5 DOFs in total: two 2-DOF (pan and tilt) for each pair of camera-project, and a 1 DOF for the rotation of the central neck. Note that the current agent unit is a carry-on type, but can be easily extended to be mobile by being mounted on a mobile platform.

2.2 Software Architecture

Based on our previous works presented in [1,2], we have designed system software shown as in Figure 2. The system is based on the client/server architecture, and configured into three parts: an agent unit, environments and a control unit. We give a brief overview of these subsystems, and the technology details of each subsystem are not explained in this paper.

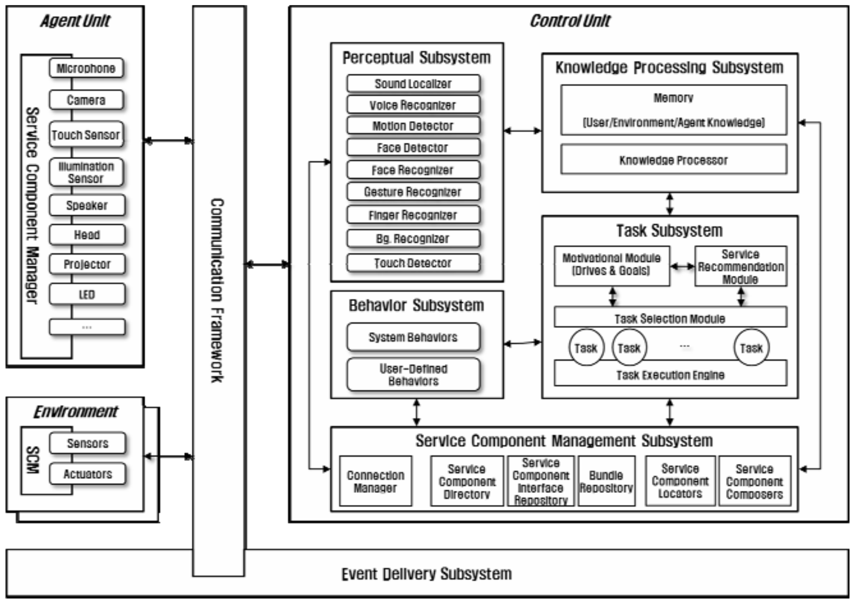


Fig. 2. The architecture of system software

Service Component Manager is the client-side software framework which is installed in the home server or personal devices as well as the agent unit. *Service Component* is a software module that represents a physical or logical device such as a sensor or an actuator. The *Service Component Manager* gathers sensing data from physical sensors in the environment as well as an agent unit and sends them to the *Perceptual Subsystem* in the control unit. It also receives control commands from the *Task Subsystem* and controls devices in the agent unit and the environment.

The *Communication Framework* provides facilities for supporting communication between the *Service Component Managers* and the server-side subsystems in the control unit. It uses a remote procedure call mechanism by the TCP protocol and binary message encoding.

Event Delivery Subsystem generates and manages events from physically distributed environments and the agent unit, and is responsible for exchanging messages among subsystems through event channels.

Service Component Management Framework is the server-side software framework to connect several *Service Component Managers* and manage the lifecycle of all service components in client and server-side at runtime. It especially supports a function augmentation by composing several components into a compound component.

In the *Perceptual Subsystem*, sensing information from the *Service Component Manager* are processed in order to acquire high-level context information. It consists of sound localizer, voice recognizer, motion detector, face detector, face recognizer, gesture recognizer and so on.

Knowledge processing subsystem plays a role of a central memory to manage context information of user, environment and task by filtering or aggregating the information from the *Perceptual Subsystem*. It provides application developers with common context ontology including places, users, devices, objects, tasks and services.

Task Subsystem is in charge of task selection and execution, which may be initiated by user commands, sensed environment information and its own motivation. The system manages its own drives and goals in the motivation module. Each drive activates a goal when any drive leaves its homeostatic range. The service recommendation module estimates the user's preferred services according to the current context and the user preferences. The current context, namely the time, the location, nearby objects and user's activity, is extracted from different modules in *Perceptual Subsystem*. The knowledge about the user's service preferences is accumulated on *Knowledge Processing Module*. It is also learned through user's feedback to the system when the user opts to react to the provided service. Task selection module selects the appropriate sets of behaviors to achieve a goal. All tasks are executed on the task execution engine.

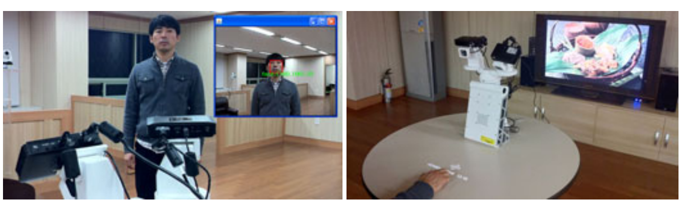
3 System Implementation

Based on the design and architecture described above, we developed a proof-of-concept prototype. We set up four application scenarios as shown in Table 1 to assess the feasibility of the key features of the robotic computer in various aspects such as user interaction and task execution.

Table 1. Four scenarios to assess the proposed concept

Subject	Functional Scenarios
Situation-Awareness	While monitoring the situation of users and environments, it responses to user's requests based on the current context.
Table-Top Anywhere	It provides an interactive workspace by providing a table-top user interface in various environments.
Bridge Physical & Virtual Worlds	It understands the usage of everyday objects and the related user's intention.
Learning User Behavior	It recommends a service by learning user behaviors through long-term interaction with users.

Figure 4 shows working examples of four scenarios using the prototype. (Video demo can be found in [3].)



(a) Context-awareness of the user and the environment

Fig. 3. Experiments using four typical scenarios

(b) Table-top anywhere

(c) Bridge physical & virtual world

(d) User behavior learning

Fig. 3. (*continued*)

4 Conclusions

We have proposed a novel concept of the future robotic computer based on the motivation of using a robot-like device a mediator in smart environments. According to the demonstration, it has been shown that more natural and convenient interaction is possible by using multi-modal interfaces including voice, gesture and virtual interfaces. This feature is amplified by the awareness of user and environment situations. Moreover, the future robotic computer is based on a software architecture that supports autonomous and evolutionary behaviors through learning and managing the long-term relationships with users. We expect that the proposed robotic computer can be realized as a personal companion in the near future, not a personal computer of today.

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Design Considerations for Assistive Platforms in Ambient Computing for Disabled People - Wheelchair in an Ambient Environment

Marwa Hassan[1,2], Imad Mougharbel[1], Nada Meskawi[1], Jean-Yves Tigli[2], and Michel Riveill[2]

[1] Lebanese University, Faculty of Engineering, Campus Rafic Hariri, Hadath, Lebanon
{imadmoug,marwa.hassan}@ul.edu.lb
[2] Nice University Sophia Antipolis, Polytech'Nice, Sophia 930 route des colles, France
{tigli,riveill}@polytech.unice.fr

Abstract. A new architecture is suggested in this paper for an Assistive Platform in an Ambient Computing for elderly or disabled people. In this situation, interaction between the user, the environment and the platform is guided by means of a generated process. Depending on the context, the elements of the process are dynamically assembled. The aspect of assembly is based on rules that are set through an online learning operation. This new approach of designing an assistive platform is validated through devices integrated in a powered wheelchair with those implemented within the environment. Rules of operation evolve depending on a data base which is continuously updated depending on user's daily activities.

Keywords: Disabled, elderly, assistive, ambient computing, aspect of assembly.

1 Introduction

The demographic evolution is going toward an aged population [1] which increases the number of the elderly and the handicapped persons. In this situation assistive devices are more and more developed**.** Actually, these devices operate in a specific environment according to specific rules. This is a major drawback since it limits the margin of the device operation and also it requires design effort. To overcome these limitations, this study proposes a new architecture for such platforms operating within an ambient computing. Because wheelchairs are widely used, this paper considers devices integrated on intelligent powered wheelchairs in order to validate the suggested architecture. In the first section existing design approaches of assistive platforms based on powered wheelchairs are categorized and their limitations are listed. In the second section intelligent environments are presented focusing on their characteristics that may help to design the suggested Assistive Platform in Ambient Computing (APAC) architecture. Section three describes the APAC architecture, section four shows its validity and section five provides a conclusion.

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2 Assistive Platforms

A bibliographic study shows that devices of a powered wheelchair (a widely used assistive platform) or of any other assistive platform interact between each other according to three different design approaches.

As shown in figure 1, in the first design approach, control commands or detected information are directly interpreted by interfaces and transferred to the output systems. Research is actually focusing on interfaces where EMG or EOG signals are detected as mentioned in [2] and [3] and many other.

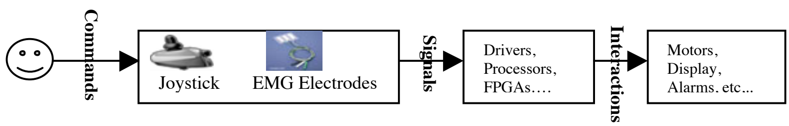

Fig. 1. Schematic for direct commands

This design approach has serious disadvantage that consists in performing a redesign, a reconfiguration and a readjustment for each special driver needs.

In figure 2, the second design approach is based on robotic systems where the driver has minimum intervention and the driving process is guided by algorithms and data acquisitions like in Sharioto wheelchair mentioned in [4]. But this design approach is not appreciated by drivers who need to possess the driving control.

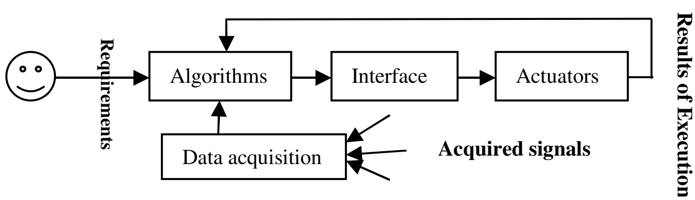

Fig. 2. Robotic design approach for assistive platforms

The third approach, concerns intelligent platforms where interactions between the environment and platform devices are provided, like in IntellWheels MMI [5].

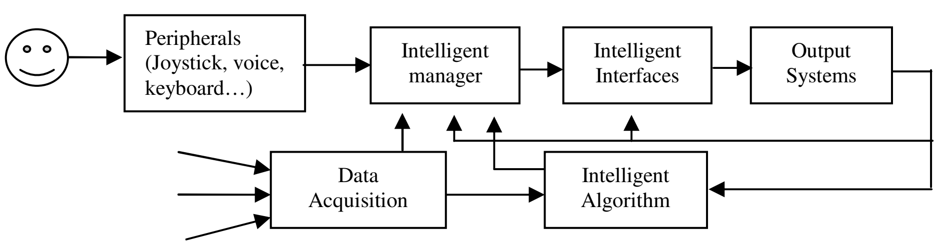

Fig. 3. Intelligent design approach

Figure 3 represents an intelligent design approach where real time interactions exist between components, algorithmic execution and adaptation process.

Algorithms in these systems are based on predefined fixed rules. APAC architecture is close to this design approach but algorithms and rules are aspect oriented and dynamically adjusted. In the APAC architecture, elements of the process are assembled according to the dynamic change of the environmental context.

3 Intelligent Environments Used for Assistance

This section shows that assistive platforms could be used in an intelligent environment. This study concerns only Ambient Assisted Living Environments (AALE) for elderly and disabled people. Works in this domain show that services provided within AALE are classified according to three categories: emergency services, services for improving autonomy and services that provide comfort.

Detection, prevention or prediction operations may produce events that launch emergency services. Sudden falls, dangerous health status, abnormal operation of the platform are situations that require an emergency service as described in [6] and [7].

Assistance provided for eating, drinking, dressing and taking medication are examples of services within the second category.

Services of the comfort category are not essential for the user requirements. Therefore, if this kind of services is provided with previous categories, they should affect neither the architectural design nor the system performance.

4 The APAC Architectures

Practically, APAC architecture consists of ambient interactive devices (sensors/ actuators) distributed in an intelligent environment. These devices interact through a central processor (server). WCOMP [8] middleware is installed on the server in addition to the device interfaces and the algorithms for data collection from the environment. Indeed WCOMP is a middleware that allows composing numerous services of devices and adapting at runtime the overall application according to the variations of the environment.

The ambient devices (sensors/actuators) in the suggested APAC are built according to the universal plug and play protocol (UPnP). This is why these devices are automatically recognized and do not need a pre-configuration process. Thus, when a new UPnP device enters the ambient environment it is detected by the middleware and according to the context the adaptation code (AA) is deployed where it is needed. The AA process has four steps: 1- selection of aspects, 2- pointcut matching, 3- composition and merging and 4- translation to elementary modifications. In the suggested APAC these steps are automatically executed via a learning process.

As shown in figure 4, environmental information is continuously collected through intelligent implemented sensors. Based on this information, the context of operation is defined by means of an intelligent machine learning algorithm. Within this defined context, a process is assembled and executed on a main server where data mining and filtering is performed. Activities of the assistive platform and of the ambient devices are monitored for generating training samples for the learning algorithm. The result will be a set of rules that are used in order to automatically generate the aspect of assembly (AA) code providing the adaptation mechanism.

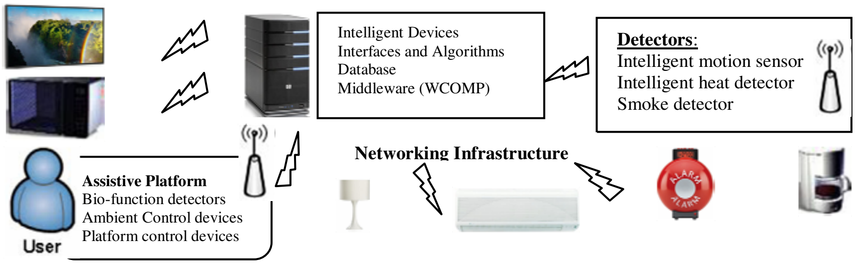

Fig. 4. Intelligent devices implemented in APAC architecture

5 Scenarios Running on APAC

The suggested architecture for the APAC takes into consideration the three categories of design approaches and provides the three categories of services.

In APAC architecture the assistive platform is considered mobile as it is the case of a wheelchair platform. Devices implemented on this platform are recognized when the wheelchair enters the intelligent environment. These devices are continuously monitored on the server where a database is dynamically updated.

As it is mentioned above, a training period is necessary before doing the automatic association between devices. But the user has the possibility to deny services offered by the system. Of course, this denial will be registered for later operations related to match between devices.

Suppose now that the user needs to use his intelligent wheelchair joystick to control a game that runs on a TV. When he asks for services, he can see on his display if it is possible or not. In case it is so, he accepts the service and starts playing. During this time, an intelligent fire detector is activated. An emergency procedure is launched and an initial emergency affectation of tasks to devices is performed. Therefore, automatically a new code is assembled and redeployed in order to make the joystick no more valid for playing the game, but for controlling the wheelchair. This scenario could be performed over the suggested APAC architecture because the aspect of assembly is also guided by events and priorities. Some of these priority rules are fixed and predefined but some other are set by the learning process.

6 Conclusion

This study has suggested a new architecture for assistive platforms in an ambient computing. It could offer a wide range of services that are discovered when the platform enters an intelligent environment. These services are realized by means of components' assembly process that is guided by online learning sessions and managed by events and priorities.

Some scenarios presented at the end of this paper show how much this suggestion decreases the cost of assistive platforms mainly when a same device is used for multiple purposes. Design and maintenance cost is also reduced because all software devices are designed according to the same architectural standard, and the maintenance concerns the hardware device independently on the other devices and on the application.

The complete implementation of the suggested architecture will be done step by step in the future. It will start with an implementation using the aspect of assembly on services to be offered. Then, it will end with a learning process in order to guide intelligently this aspect.

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Establishing a Common Service Platform for Smart Living: Challenges and a Research Agenda

Fatemeh Nikayin[1], Danai Skournetou[2], and Mark De Reuver[1]

[1] Delft University of Technology
{f.a.nikayin,g.a.dereuver}@tudelft.nl
[2] Tampere University of Technology
danai.skournetou@tut.fi

Abstract. The vision of smart living promises innovative services from providers in energy, healthcare, entertainment and surveillance sectors. While smart homes used to equal home automation, evolving ICT technologies now enable truly adaptive and intelligent services that are integrated in several industries. Sector-specific service platforms are emerging that provide basic intelligence for services. However, smart living services should not be constrained to a specific industry sector, and hence the service platforms should be easily accessible for service providers regardless of their industry. In addition, smart living services should not be constrained to residents within the home, but should take advantage of outdoors position information to open up a range of novel service concepts. Establishing such a vision of smart living involves various technological and organizational challenges. This paper gives an overview of the current service platforms for smart homes and positioning information. Based on this overview, we propose a research agenda for enabling smart living services. The two major issues are how to achieve collective action between players from multiple sectors in order to set up a common service platform, and how to design business models that allow adding GNSS-based positioning information to the service platform.

Keywords: Smart homes, service platform, service innovation, location based services.

1 Introduction

We are entering an era of Smart Living, in which simple home automation (i.e., domotica) is moving towards increasingly advanced smart entertainment, health support and energy management services [1], [2], [3] and [4]. Obviously, what is "smart" depends on time [5]. In the 1980s, the "smartness" of smart home concepts merely involved predefined automation of appliance tasks [6]. Since the year 2000, smartness involves much more flexible task automation adapting to the situation based on past usage data, user preferences and interaction with other devices.

Service providers from different sectors have become interested to offer smart home services. For example, energy providers are developing smart metering tools which enable users to control their energy consumption and reduce their electricity

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bill [7]. Service providers in healthcare sector are looking into services to facilitate a safe and independent living for elderly and disabled people [8], [9], [10]. Media and telecom companies are providing a wide range of entertainment and communication services, for example, audio and video [11]. Notably, different platforms used to offer these smart home services and each one is restricted to a particular sector rather than many sectors.

Within a large-scale ongoing research project TRANS (Trans sector Research Academy for complex Networks and Services), we aim to move from smart home services to the concept of smart living (SL). Focusing on residents rather than sectors, , our vision of smart living entails two main leaps from current situation. Firstly, developing interoperable and open service platforms to enable fast and cost efficient service development, regardless of the industry sector offering them. Secondly, using information on user's location to develop and offer more intelligent services accessible anytime and anywhere. A specific enabler of this second leap is the integration of Global Navigation Satellite System (GNSS) based receivers in mobile devices. Nevertheless, to achieve such vision of smart living, various technological and organizational challenges lie ahead. This paper reviews the state-of-the-art in smart living platforms and proposes research directions to tackle current challenges.

2 Current Smart Home Service Platforms

Technically, a service platform is a combination of hardware architecture, network, an operating system or a software framework that is required to offer services to end users. Such service platform usually includes several components required by the services running on that platform, and which those services would otherwise need to include themselves [12]. Sharing hardware and software saves resources for developers in writing applications on top of the platforms [13]. From economic point of view, a platform creates a two-sided market in which the number of users influences service providers to develop services for the platform and on the other side users only pay for a platform with plenty of services on it [12]. Such multi-sided platform, "generally faces a critical mass constraint that must be satisfied if the business is to be viable" [14].

Currently, service providers in energy, healthcare, security and entertainment are offering multiple platforms for smart home services. Table 1 provides an overview of a number of major existing services and service platforms (hardware and software requirements) in smart home domain, based on desk research and interviews.

As we can see in the table, typically smart home services are provided using a service platform at home which connects several sensors and detectors and communication modules to transmit data between service providers and service users. Such service platform may consists of generic service elements like authorization, authentication and security. The wide availability of broadband connection and advanced technologies like SOA and cloud computing could enable service providers to share the generic functionalities that are required for multiple service offering. Besides, they could share the basic hardware and technology (e.g. network and devices) for service delivery at home. For example, a home gateway could be connected to all home devices and could be used not only for internet access and IPTV services, but also for controlling security, energy consumption and/or access to health-care services. We refer to that collection of shared functionalities and technologies to offer smart living services with the term *common service platform (CSP)*. Such CSP could tremendously reduce the time and cost of service offering and foster service innovation by enabling service providers to offer new applications and services.

Table 1. Overview of major sector-specific service platforms for smart home services

	Service Platform	**Wireless sensors and devices**	**Data network and Standards**
Energy	Smart metering devices. Examples: AlertMe hub, Wattson hub, PG&E's SmartMeter™, Emerson smart thermostats, GE's smart meters	Motion, thermal, light (IR), humidity, high electrical usage, leaky pipes	Mobile: GPRS, CDMA Fixed: Power Line Communication (PLC)
Health	Monitoring and communication systems Examples: HOPE smart platform (supported by Philips), Philips Telestation, ZyXEL smart home gateway	Motion, body wearable sensor , thermal, light (IR), video camera, blood-sugar or heart rate readings	Mobile: 3G/4G Fixed: DSL/Cable
Security	Security alarm system Examples: uControl SMA Platform, Shaspa Smart Home Kit, WoonVeilig	Motion, sound, video cameras, smoke, gas, water leakage, door	Fixed: ADSL, Cable Legacy security networks
Enter-tainment	Home gateways, receivers, modems, TV Examples: Philips Net TV, Polycom Telepresence, Android-powered Google TV Game consoles Examples: PlayStation, Xbox	Light (IR),motion, occupancy	Fixed: DSL, Cable, FTTH, TCP/IP, DVB-C, DOCSIS Multimedia over Coax Alliance (MoCA®), Internet Protocol Television (IPTV)

As smart living implies mobile extensions, a major advance would be to complement such common service platform with location information. The service platforms needed to do so are discussed in the next section.

3 Service Platforms for Location Information

Basic smart home concepts assume that the user is at home, controlling its appliances and smart home applications. Using mobile smartphones, smart living services can be accessed without any restrictions on place and time. Besides proactive actions from the resident, smart living services could also automatically adapt to information on the whereabouts of the resident, for example using indoor sensor networks. Mobile technologies add another dimension to this idea, as smart phones are commonly equipped with GNSS receivers which allow computing their outdoor location with or without the mobile network's assistance. See [15] for an overview of the possible positioning technologies. As such, the availability of a resident's outdoor position anytime enables novel smart living services.

These location-enabled smart living services require several service platforms that should interoperate with the smart living platform. For positioning information, issues such as outdoor accuracy, coverage and availability are critical.

Alongside the technology for computing the mobile's coordinates in the x-y-z plane, their translation into a format understandable by the users is necessary. For this purpose, map and Point Of Interest (POI) databases as well as functions enabling the translation of the GNSS coordinates into an addressable point on the map and vice versa (known as geocoding and reverse geocoding, respectively) are needed. Furthermore, routing algorithms for optimized navigation from point A to point B based on user's preferences (e.g., find the shortest or fastest route) are vital in the provision of smart living services. Google Maps is commonly used platform which offers the above-mentioned functionalities and also allows the creation of new map-based applications.

4 Challenges and a Research Agenda

In this paper, we argue to move from smart homes to smart living by developing *common service platforms* that are independent of the industry sector, and that incorporate information on the whereabouts of residents even if they are not at home. Realizing such vision entails several challenges that require further research.

Although a common service platform for smart living could be technologically distributed over parties, it demands collaboration of providers in various sectors to contribute required resources and information. However, investing a lot of money and efforts and sharing huge amount of information raises several concerns. From technical point of view, management, security and privacy of data, and from organizational perspective, sharing investment and risks and preventing free-riders are crucial issues. As collaboration is required between parties from different sectors, role division conflicts, differing expectations and strategic motives might appear. One of the most important issues is the strategic interests of parties over the ownership of such platform.

Equally important is the role of a leader to build up trust and motivate parties to mobilize collaboration for a common service platform. Besides the characteristics of the leader, such as trustworthy and reputation, the technical characteristics of platform, such as openness or closeness, may have impact on achieving "critical mass" of highly resourceful and interested contributors for the platform. Our future research aims to study these issues using collective action theory, which provides a theoretical lens for framing the strategic interests and behavior of several interdependent actors [16].

Adding location information to such common service platform enables more advanced smart living services, but also raises several challenges. Privacy has been a major issue in the adoption of location-based services because sensitive position information is concealed to other parties within or outside user's social environment. Certain services may be more intrusive than others for example, if they require continuous monitoring of user's position. Under the location privacy umbrella, several questions are relevant, such as what parties can have access to location data, if and when should a person's consent be required and how to protect users' privacy. Moreover, issues such as where the position of the users should be stored, what methods should be used to access, control and protect the location data and how to react in the event of a malicious attack should be well-examined. Alongside the privacy and security, business models, pricing strategies as well as customer demand for location-enabled smart living services provide further challenges. The accuracy and reliability of various positioning methods, ranging from GPS to more advanced Galileo systems, is a crucial issue that will determine usefulness and viability of the smart living services. In our future research, we specifically aim to study the business model for GNSS enabled smart living services.

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Handling User Interface Plasticity in Assistive Environment: UbiSMART Framework

Thibaut Tiberghien[1], Mounir Mokhtari[1,2], Hamdi Aloulou[1], Jit Biswas[3], Jiaqi Zhu[3], and Vwen Yen Lee[3]

[1] CNRS, Image & Pervasive Access Lab (IPAL UMI), Singapore
{thibaut.tiberghien,mounir.mokhtari,hamdi.aloulou}@ipal.cnrs.fr
[2] Institut TELECOM, France
[3] Institute for Infocomm Research (I^2R/A*STAR), Singapore
{biswas,jzhu,vyalee}@i2r.a-star.edu.sg

Abstract. In this paper, we present the UbiSMART (Ubiquitous Service MAnagement and Reasoning archiTecture) framework that aims to provide a highly flexible context-aware service interaction mechanism. Pervasive computing enables assistive environments with extensive possibilities, especially when seizing opportunities to enhance quality of life for ageing people with dementia. However, we have to design novel interfaces to aid the engagement of targeted users towards the provided services. A natural, seamless interactive experience must be created. Our focus lies mainly on the reasoning mechanisms performing user interface plasticity, i.e. context-aware adaptation of the interaction to create a seamless user experience.

Keywords: Ambient Assisted Living, Ageing People with Dementia, Pervasive Access, User Interface Plasticity, Semantic Reasoning.

1 Introduction

Making use of the transition towards pervasive, ubiquitous environments where embedded computing devices seamlessly integrate and cooperate to serve human needs, we can design systems specially fitted to provide care to the elderly. There is indeed no reason for the elderly to miss out on the benefits of such technologies which can help them remain independent, socially active and increase their mobility and safety. These technologies are particularly relevant to elderly people with dementia, who are usually accepting of their deployment and understand the impact on their safety and well-being in daily life [5].

To provide dependant people with assistance in their living space, we deploy a service provision platform they can choose services from or that could even automatically select relevant services and then establish the right personalized interaction. To enable this computational selection of services, a sensing infrastructure must be embedded in the environment and mechanisms defined to represent and infer context information. Reasoning mechanisms then select the services and deliver then to familiar devices such as TV in a personalized and seamless way.

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Below we introduce our particular research approach describing the UbiSMART framework that incorporates modules to handle the different aspects mentioned above. We will then focus on the design of seamlessly pervasive user interfaces enabled by semantic reasoning.

2 Methodology

As explained in the introduction, we aim to build a service platform that is context-aware and provides services with an adapted user interface. After a requirements gathering session [1], we have adopted a research approach on two complementary fronts: designing a flexible service provisioning framework called UbiSMART, which is presented here, and a micro-context acquisition architecture based on lightweight, non-invasive sensors, which will be detailed in a different paper. These two platforms are independent and collaborate seamlessly through an abstracted event communication bus.

UbiSMART Framework

The UbiSMART (Ubiquitous Service MAnagement and Reasoning archiTecture) framework is to be considered as an infrastructure to ease integration and deployment of ambient assistive living (AAL) technologies. As illustrated in figure 1, the UbiSMART framework addresses three main aspects (context awareness, service management and service delivery) refined in several collaborative modules. Modules share a semantic knowledge base (KB) on a producer-consumer basis; each producer provides a semantic description of its contribution, thus all consumers can make sense of it. The KB inferred by producers using description logic rules is then queried by consumers.

Building a flexible and easily deployable AAL system comprises some challenges [4]. First, the system has to react to users' needs with services relevantly provided in real-time. This means that it should be able to detect the context of users, e.g. location, activity, problem faced, etc. The *context understanding module* (see figure 1) coupled with our sensor network enables context acquisition, activity recognition and a reasoning engine synthesizes context knowledge. Then, we must administrate a list of services described semantically and a reasoning engine performs semantic matching to select services that are useful to users in real-time. This is supported by our *service selection module*. Finally, the interaction must be built between users and services in a way that fits targeted users. The *user interface plasticity module* adapts the interaction to users' characteristics and their context of use, and then bring it in their area of focus. These three modules, though independent research efforts, share some common aspects like the semantic description of the environment, or the reasoning mechanisms used to infer available knowledge. The next section will detail these key challenges, taking the example of the user interface plasticity module. Some more common aspects, like the seamless communication with distributed resources, even a priori unknown ones, are not treated here.

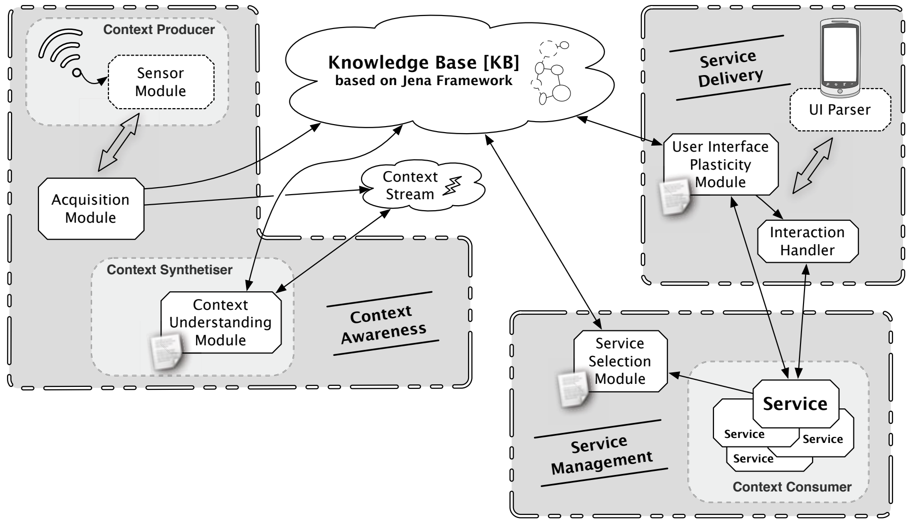

Fig. 1. Architecture of the UbiSMART platform

3 User Interface Plasticity

When designing service interaction for elderly people with dementia, there are several requirements to consider. *Polymorphism* [2] characterizes the adaptation needed knowing that physical and intellectual limitations have to be taken into account, as well as preferences in order to help users engage in interaction. The second important requirement is *multi-modality* — indeed to guide the elderly throughout their activities, services should prompt them at their point of focus so as to decrease the trouble and enhance the seamlessness of interaction. We must find mechanisms to determine this point and optimize the interaction modality accordingly. These two aspects compose our scope of the *user interface plasticity* challenge which characterizes the *"capacity of an interface to withstand variations of both the system physical characteristics and the environment while preserving usability"*[7]. We focus in this paper on the multi-modality.

Inference Engine

In the UbiSMART framework, the reasoning engines of the various modules are inferencing a shared ontological model. Engines have overlapping specific sub-models, which they infer in a collaborative way. This part will introduce the sub-model related to the modality selection module, part of the user interface plasticity module, and describe its inference principles.

We consider here elderly people in a nursing home environment with the involvement of caregivers. Sensors are embedded in the environment and provide some context information, such as location, activity being performed or problematic behaviours (deviance). Standing for context-aware services, the platform

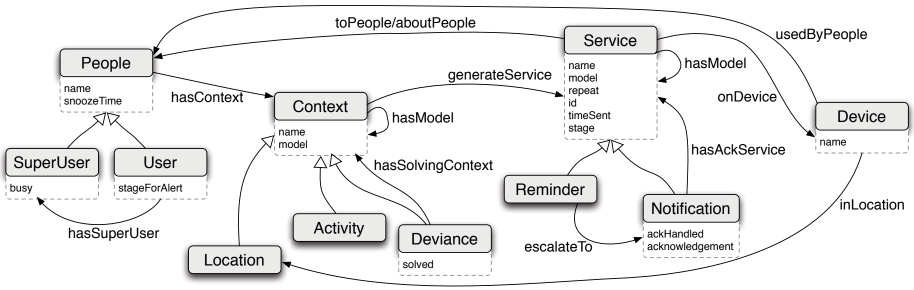

Fig. 2. Ontological sub-model used for modality selection

provides reminders (to user) or notification (to caregivers), e.g. if a person has finished showering but left on the tap, a reminder will be sent which can be escalated to a notification if ignored. As represented in figure 2, the sub-model designed contains four main classes: `People`, `Device`, `Service` and `Context`, eventually refined in subclasses; e.g. an individual of the `People` class can be a `User` or a `SuperUser` to differentiate the roles of caregivers. Users are related to their superusers by the `hasSuperUser` relation and superusers have the specific attribute `busy` that informs about their availability. In other sub-models, users have attributes to describe their habits, limitations or special needs in order to select the most relevant services. Devices are not characterized much yet, they can be related to their owner or location respectively by `usedByPeople` and `inLocation` relations. To better understand the whole system, the figure 2 pictures other relations between users, their context, services and devices.

The inference engine, based on description logic, is built on a set of first order rules like *conditions* ⇒ *inference actions*. Such rules can be written in many ways and at disparate levels of abstraction. Here lies one of the challenges of such systems: we would like rules that are simple enough to enable fast deployment, design iteration and groups of collaborative rules but complex enough to be generic, handle complex situations and keep the number of rules limited. The direction we have been taking is to characterize individuals of the model with key information that will guide the system's reaction. The rules' conditions are then set on the description of instances instead of instances themselves, which slightly abstracts the reasoning and tends to replace implementation of rules by their implementability. Examples of the type of rules used are given below:

$$\textit{service s, people p, location l, device d, activity a}$$
$$(\textit{s toPeople p}) \wedge (\textit{p hasContext l}) \wedge (\textit{d inLocation l}) \Rightarrow (\textit{s onDevice d})$$
$$(\textit{p hasContext a}) \wedge (\textit{a handsOn true}) \wedge (\textit{d handheld true}) \Rightarrow (\textit{d fitted false})$$

We first implemented this using Jena semantic web framework which includes a rule-based inference engine. However, this led us to observe some flimsy behaviours when using several rules to collaborate on the same decision. Jena has actually an incomplete integrated inference engine [6], so we tried to use Pellet as an external reasoner interfaced with Jena. Pellet had the advantage to be based on SWRL, the W3C standard semantic web rule language. This language was revealed to be limited to ask/tell queries, thus making it unfit for the inference of dynamic knowledge as inferred information cannot be then disclaimed. Our current implementation is based on the commercial reasoner RacerPro whose features have so far tackled the problems above.

4 Conclusion and Perspectives

We have presented how service-based systems in distributed environments can be enhanced using a semantic knowledge base and associated inferencing techniques. We have described how our modality selection module uses sensed and synthesized context information, as well as semantic descriptions of the ambient interactive devices, to decide which modality fits best for interaction. Our semantic approach to knowledge processing for AAL, is however revealing its limits, thus giving us interesting paths for future research. These limits are closely related to the characteristics of the knowledge processed. Context information is often ambiguous or uncertain, which leads us to integrate a quality of information metric in our representation [3] and adapting the inference accordingly. Another key issue to tackle is the unpredictability of human behaviours, particularly with people having dementia. The proposed approach to overcome this is to generate in real-time the inference rule-set through a rules factory that adapts meta-rules (higher level of abstraction) considering each contextual situation.

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Patterns Architecture for Fusion Engines

Ahmad Wehbi[1,2], Manolo Dulva Hina[1,2], Atef Zaguia[1,2], Amar Ramdane-Cherif[2], and Chakib Tadj[1]

[1] MMS Research Group, Université du Québec, École de technologie supérieure
1100, rue Notre-Dame Ouest, Montréal, Québec, H3C 1K3
[2] LISV Laboratory, Université de Versailles-Saint-Quentin-en-Yvelines
10-12, avenue de l'Europe, 78140 Vélizy-Villacoublay, France
{ahmad.wehbi,manolo-dulva.hina,atef.Zaguia}.1@etsmtl.ca,
ctadj@ele.etsmtl.ca, rca@prism.uvsq.fr

Abstract. This paper presents a design of an architecture that facilitates the work of a fusion engine. The logical combination or merging of input streams invoked by the fusion engine is based upon the definition of a set of patterns and its similarity with previously collected data from various modalities. Previous fusion engine designs had many weaknesses, among them their being specialized on a specific domain of application. The proposed architecture addresses such weakness and provides additional features, namely its ability to handle large number of modalities and due to its using knowledge base and standardization characteristics; it becomes suitable to various types of multimodal systems. The techniques used to achieve these features are discussed in this paper.

Keywords: modality, patterns, XML, data interpretation, knowledge base, normalization.

1 Introduction

As per W3C specification, a multimodal interaction activity seeks to allow users to dynamically select the most appropriate mode of interaction for their current needs, including consideration of any disability whilst enabling developers to provide an effective user interface for whichever modes the user selects. Various multimodal applications [1] are conceived and are effective solutions for users who have constraints, disabled or are on the go [2 - 5]. These applications are integrated with web services which are application functions or services [6]. Application service can be implemented as an autonomous application or as a set of applications. Engel et al [7] proposed an approach for processing modalities in a system called SmartKom [8]. Its idea is to generate all meaningful combinations after considering all hypotheses and afterwards selects the n best results which are passed to the intention analyzer. The disadvantage of this approach is that under adverse circumstances, the generation of all meaningful combinations takes too much time. Sonntag et al [9] proposed an ontological solution for a system called SmartWeb. It is based on question answering technology that combines different kinds of domain ontologies into an integrated and

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modular knowledge base. For this purpose, they defined an upper model ontology based on SUMO and DOLCE and integrated each domain ontology on it. The solution presented in this work is very limited. The architecture of HephaisTK system developed by Dumas et al [10] is based on software agents that are dispatched to manage individual modality recognizers, receive and encapsulate data from the recognizers, and send them to an individual central agent named the "postman". This postman agent centralizes all data coming from the dispatched recognizers agents in the database, and distributes the data to other interested agents. However, this architecture needs a configuration file to be specified for describing the human-machine multimodal dialog desired for the client application, and for the specification to which recognizers need to be used. Having taken these weaknesses into account, we proposed an architecture that addresses these issues. This is done through modeling patterns that deal with different modalities, and by creating a knowledge base that contains these patterns. The adoption of this architecture will facilitate the work of a fusion engine by giving it the most meaningful combinations of data.

The paper is organized as follows. In section 2, we present the architecture itself and describe its components and finally we conclude this paper in section 3.

2 Pattern Architectural Design

In synopsis, the proposed architecture provides features that allow it to handle large number of modalities, support different types of multimodal systems and facilitate the work of a fusion engine by providing it the most probable matching of data. In this section, we describe our architectural design with focus on the use of patterns as a solution to the described problems of previous systems architectures.

2.1 General Schema and Approach

A general overview of the architectural framework of multimodal fusion is shown in Figure 1. It illustrates how a user supplies input streams and the interaction of various system components leading to the merging process by the fusion engine. These system components and/or processes are as follows:

- Modalities: These are modes of human-computer interaction. Media devices can be used to receive data input from the user (e.g. cellular phone, microphone, etc.)
- Recognition: The framework identifies and recognizes data provided by different modalities by transforming them to XML or EMMA.
- Patterns: These are predefined models that describe a modality; it is composed of data format, events and parameters. Patterns are used to check a match with data associated with modalities.
- Interpretation: The framework measures the match between a given data against a registered pattern and generates the most probable combinations of data.
- Models of rules patterns: These are predefined models that describe rules needed by the fusion engine for data merging.
- Fusion: Framework logically merges data to obtain an output.
- Output: Final meaningful result obtained after data streams have been merged.

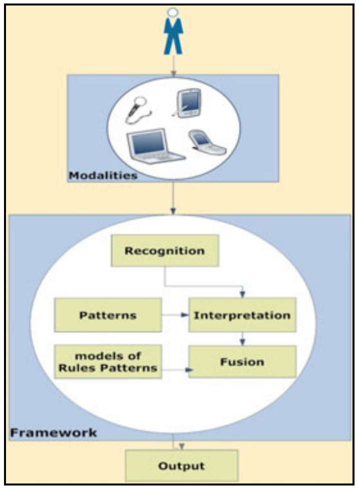

Fig. 1. Architectural framework of multimodal fusion

2.2 Overview of the Pattern's Architectural Design

The previous diagram in Figure 1 is further refined in Figure 2 showing the whole concept of the architecture. Aside from the recognition, interpretation, and fusion processes that were described earlier, the refined architectural design shows new components, namely the knowledge base and the database. The remaining system components and the description of various steps involved in the fusion process are described below:

- **Knowledge Base:** It is a container that stores the patterns as ontology concepts.
- **Database**: It is a container that stores all probable meaningful combinations of interpreted data. These combinations are used by the fusion engines.
- **Step 1 – User - Modality:** The user begins his interaction with the system, using various modalities such as voice, facial expression, etc. By performing an action, the user automatically launches/activates modalities.
- **Step 2 – Modality – Recognition of Modalities:** This module receives as input XML files containing data concerning modalities, usually captured using sensors. From each XML file, this module extracts some tag data needed for fusion. Afterwards, it creates a resulting XML containing the selected modalities and each modality's corresponding parameters. In conformity with W3C standard on XML tags for multimodal applications, we use EMMA. EMMA [11] is a generic tagging language for multimodal annotation.
- **Step 3 – Patterns – Knowledge base:** Patterns are stored as concepts in the knowledge base which contains data format, parameters and modality events. These patterns are used by the interpretation module to check a similarity match between the data provided by modalities against the patterns themselves. These concepts are semantically represented inside the knowledge base using the Web Ontology Language (OWL).

- **Step 4 – Interpretation of Modalities:** This module is responsible for checking if there is a match between the data associated with modalities and that of the patterns. Match checking is done by determining the following conditions: (1) the data format - the data format from a special modality is checked with the data format of the pattern that concerns that modality, (2) parameters – these are also checked to verify the most suitable selection of modalities, and (3) the events – this is done by comparing the present event. If the three conditions are true, two types of result are produced, namely (1) the generation of probable meaningful combinations of data, and (2) the detected modality used by the user is correct. The generated meaningful data are stored in a database which will be used later by the fusion engine.
- **Step 5 – Fusion Engine:** This module is responsible for the merging of data by gathering different input streams coming from various modalities and obtaining a meaningful combinational result. Input signals are intercepted by the fusion agent and then combined taking into account some given semantic rules.

2.3 Context Pattern

A pattern is defined as an idea that has been proven to be useful in one practical context and therefore will probably be useful in others [12]. Patterns are often defined as something strictly described and commonly available. In our work, a pattern is composed of data format, events and parameters. Patterns are used to check a match of a user action involving a modality against the pre-defined data associated with modalities. Patterns are modeled, taking into account important characteristics, namely, the format of the pattern, its parameters and the modality events. Patterns are stored in a knowledge base.

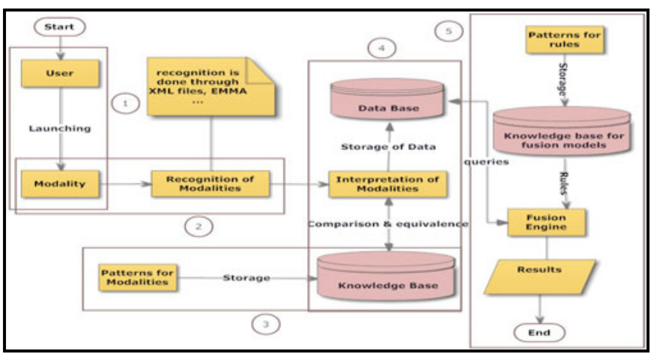

Fig. 2. Architecture overview

2.4 Models of Rules

Another type of pattern is needed in our architecture. This pattern contains the *Models of rules* needed for data merging and it is stored in a knowledge base. A multimodal fusion rule consists of constraints and result construction rules. Patterns are modeled, taking into account important characteristics, namely, Content, Category, Constraints, Time, Probability and Modality.

3 Conclusion

In this paper, we presented an architecture that is very useful in a multimodal system. The architecture proposes a solution that standardizes the interpretation of modalities. Such standardization is implemented by defining a set of patterns that are stored in a knowledge base; these patterns, implemented using OWL semantic web language, take into account special data formats, parameters, events and models of rules that are associated to modalities. This paper proposes a new solution by modeling an architecture that facilitates the work of a fusion engine, using predefined patterns stored in a knowledge base or ontology. These patterns will be a reference that measures the similarity between data that was previously taken from different modalities and the pattern itself. This technique will offer the fusion engine the most meaningful combination of data that can be used in the fusion process.

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BlindShopping: Enabling Accessible Shopping for Visually Impaired People through Mobile Technologies

Diego López-de-Ipiña, Tania Lorido, and Unai López

Deusto Institute of Technology – DeustoTech, University of Deusto
Avda. Universidades 24, 48007 Bilbao, Spain
{dipina,tania.lorido,unai.lopez}@deusto.es

Abstract. BlindShopping is a mobile low-cost easily-deployable system devised to allow visually impaired people to do shopping autonomously within a supermarket. Its main contributions are: a) a user navigation component combining an RFID reader on the tip of a white cane and mobile technology, and b) a product recognition component that uses embossed QR codes placed on product shelves and an Android phone camera for their identification. Furthermore, it provides a web-based management component to easily configure the system, generating and binding barcode tags for product shelves and RFID tag markers attached to the supermarket floor.

Keywords: Blind, Navigation, Mobile Computing, QR codes, Web-Services.

1 Introduction

Accessibility describes the degree to which a device or environment is available for every person. Nowadays, this term is more and more present in our society, as it is considered a fundamental right. On the other hand, technology seems to be invading every aspect of our lives, but it is also moving away from or not giving service to those collectives which most need it.

The PIRAmIDE project[1] addresses this issue by taking advantage of smartphones potential to behave as disabled users' sensorial complement. Its aim is to enable the smartphone-mediated interaction of a user with the ecosystem of services populating an environment (e.g. home or supermarket). Thus, PIRAmIDE allows disabled people to perform daily life tasks autonomously and independently of their disability (e.g. blind, deaf or elderly people). Mobile devices are transformed into sense enhancers giving a 6th sense to those who already enjoy their five functional senses, but more importantly, complementing those which have some sensorial impairment.

One of the concrete application domains targeted by PIRAmIDE is overcoming the difficulties blind people usually encounter whilst shopping in a supermarket without the help of someone else. This paper presents an inexpensive easily-deployable solution which makes use of off-the-shelf technology (mainly smartphones).

From our point of view, an accessible shopping solution has to fulfil the following requirements if a feasible and flexible wide deployment wants to be achieved:

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- *Conventional shopping behaviour should not be altered.* Many available solutions require the user to establish her shopping list before initiating the purchasing process (planned shopping). In most cases, such an approach is more efficient but it is less enjoyable since the user, in this case the blind person, cannot actually browse the products of the supermarket, discover new brands or new product types, i.e. carry out opportunistic shopping. In fact, what we actually wish to do is mixed shopping, i.e. something in between planned and opportunistic shopping.
- *Minimal additional off-the-shelf infrastructure should be introduced in supermarkets.* Supermarkets are reluctant to introduce complex changes in their internal information management systems. Furthermore, only simple low-cost easily maintainable physical instrumentation of their purchasing surface including aisles and shelves is acceptable. Any feasible solution should leave products as they are, i.e. such solution must be able of recognizing and deal with the standard UPC barcodes utilized in worldwide retail. It is a must that accessible shopping systems operate in actual supermarkets with all their restrictions.
- *Blind people should use their usual devices.* A blind person carries with her a white cane and a mobile phone. Therefore, if any, those are the elements that may be modified or enhanced in order to allow a blind person to safely and effectively carry out her shopping. Only inexpensive off-the-shelf already known technology by the blind should be considered to ensure wider acceptance.

2 The BlindShopping Platform

Our solution aims to offer eyes-free technological support for blind people to shop around as if they saw, without altering conventional shopping patterns. It is designed to avoid overloading the visually-impaired person with additional new gadgets and enforcing a supermarket to go through heavy and costly, both in price and time, installation and maintenance processes.

The assumptions taken by BlindShopping regarding a supermarket organization are as follows. First, it is considered that all products are grouped into different product categories (e.g. drinks), and these are divided into product types (e.g. drinks/cola) which again are divided into concrete brand products (e.g. Pepsi can). Apart from that, the supermarket is divided into cells of two main types: cells containing shelves and passageway cells. Thus, internally, BlindShopping maps the IDs of the RFID tags within a cell to navigation and product location information such as the type of a given cell, its neighbour cell types, and in case of being shelf type cells, the product category, types and concrete products located in that area.

BlindShopping offers infrastructural support for the whole purchasing process within a supermarket, understood as a four step cyclic process: *product category navigation/product search/product identification/product selection*. Such cycle is broken when the user decides to go to the cash till to pay for her purchases. Consequently, BlindShopping offers a *navigation* component driving the user through voice messages to the aisle where a product category previously dictated to her smartphone is located. Once there, BlindShopping also offers support for *product recognition* by either shelf section identification or product own identification by means of QR or UPC code scanning, respectively.

Fig. 1. Navigation system (left), UPC code recognition (middle) and QR-code recognition

2.1 BlindShopping Architecture

The distributed component architecture of BlindShopping is composed of the following three components:

1. *Navigation system*. It is in charge of guiding the blind user inside the supermarket. It provides through a headphone connected to her smartphone simple verbal navigation instructions. It combines a white cane with a portable RFID reader attached to its tip, a set of road mark-like RFID tag lines distributed throughout the corridors of the supermarket (see left hand side of Fig. 1 and top part of Fig. 2, respectively) and a smartphone application processing the RFID readings received though Bluetooth and generating user navigation verbal commands as result.

Fig. 2. RFID tag marking (top), Motorola Milestone and HTC Desire Android devices (left), Baracoda's Pencil2 barcode recognizer and IDBlue RFID reader (middle), NFC 6131 NFC device (right) and QR-Code and standard UPC barcode (bottom centre)

2. *Product recognition*. Once the user reaches the target product section, she points with her camera phone (see Fig. 1) to an embossed QR [2] or UPC code attached to a shelf section or product. The smartphone camera recognizes that code and then informs verbally about the product main features. Note that a QR code can encode up-to 4296 alphanumeric characters, and its redundancy makes successful reading possible even when partial images of them are captured.
3. *System management*: BlindShopping includes a web front-end for BlindShopping RFID and QR code infrastructure management. It allows the registration of

the collection of RFID tags scattered though the supermarket floor and the QR-codes attached to products or shelf sections.

2.2 Implementation Details

A Nokia 6131 NFC was used, initially, for reading RFID tag floor markings and deliver them through a Java ME Bluetooth application to a user-carrying Android phone. An alternative implementation using the autonomous Baracoda Tagrunner[1] RFID Bluetooth reader has then been used.

The mobile application in an Android phone allows the blind person to choose an action through a gesture interface or by issuing a voice command. Concretely, the navigation system operation is requested by drawing an “L” or issuing the “Location” voice command (see Fig. 3). Drawing a “P” or issuing a “Product” voice command, the user will access the product recognition component that allows obtaining information about a product.

A backend server contains the system data and business logic of the BlindShopping platform. In a real deployment, this back-end should be integrated with the inventory management system of the supermarket.

Fig. 3. User drawing a “P” (left) on Motorola Milestone, Nokia 6131 NFC to read HF RFID tag for navigation and supermarket mock-up for testing (right)

3 Related Work

An exhaustive comparative study of existing accessible shopping systems for blind and visually impaired people was carried out by Kulyukin and Kutiyanawala [3] in 2010. ShopTalk [4] is a wearable solution that requires the user to carry a barcode scanner and a UMPC in a backpack. Verbal route instructions are issued through a headphone connected to the UMPC at the blind person’s backpack. Although the supermarket does not need to install and maintain any hardware, the system requires access to the supermarket’s inventory control system and binding of product barcodes into supermarket locations so that guiding can be accomplished. The advantage of BlindShopping is that it only demands a lightweight smartphone equipped with a camera to read QR Codes attached to shelf sections and the very blind person’s white cane enhanced with an off-the-shelf RFID reader.

[1] http://www.baracoda.com/baracoda/product/ p_48_TagRunners.html

The Tinetra[5] project offers the possibility of detecting products via a barcode or RFID reader, and then it obtains related information via GPRS from the server. However, it does not include a guiding system as BlindShopping. Similarly to us they use Baracoda's Pencil2 to scan barcodes and IDBlue to scan RFID tags.

4 Conclusions and Further Work

A basic usability study with a blind person has been carried out. She was requested to navigate through different sections of our emulated supermarket surface by using her white cane with an attached BT RFID reader and an Android application on an HTC Desire. Her main comment was that navigation was very intuitive since locating the RFID tag markings was very easy and the navigation vocal commands very useful to reach the desired target. She was then requested to assess whether locating embossed UPC barcodes and using a Baracoda Pencil2 device to recognize them (see centre of Fig. 1) was easier or harder than using the Android phone camera to point to embossed QR codes located over products (see right hand side of Fig. 1). She judged that the latter was much more plausible. Besides, QR code recognition using a camera phone is much faster and reliable.

BlindShopping is a low-cost easily deployable solution which makes a supermarket accessible to visually-impaired people through two core components: a) an RFID and mobile phone based indoor navigation system and b) a mobile QR-code based product recognizer. Future work will undertake a fully fledge evaluation in a real supermarket.

Acknowledgments

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Maisons Vill'Âge®: Smart Use of Home Automation for Healthy Aging

Shahram Nourizadeh[1,2] and Claude Deroussent[2]

[1] INPL - Nancy University, Loria, France
[2] MEDeTIC, France
Shahram.Nourizadeh@Loria.fr,
{Shahram.Nourizadeh,Claude.Deroussent}@medetic.com

Abstract. As part of a PhD thesis at the Loria research center, National Polytechnic Institute of Lorraine (INPL), "Maisons Vill'Âge®" a new concept of building smart home by integrating telehealthcare and home automation systems, is developed in France. The segment of population, we are targeting is the senior citizens. The healthcare system uses home automation sensors and other environmental sensors like bed and chair sensors to monitor the activity level of the elderly. Activity patterns are analyzed by an intelligent application which is based on Fuzzy Logic to find any unusual behavior. The system is also equipped with wireless medical sensors to monitor the health situation of the elderly; it uses also a wireless sensor network to detect falls. The system detects health abnormalities at an early stage through the frequent monitoring of physiological data. This paper presents a brief description of the system.

Keywords: Telehomecare, Smart home, Context-aware computing, Home automation, Activity monitoring.

1 Introduction

Technologies exist to help people deal with a reduction or loss of mobility, vision, hearing, and cognitive ability; to continuously monitor vital parameters; to reduce accidents by anticipating risky situations; and to deliver therapy through wearable biomedical sensors. In this respect, smart homes are being used to maintain safety and independence among elderly and to provide home-based eHealth and telehomecare services. The concept of home-based eHealth that includes both telehomecare and the smart home is introduced in [1]. In this context, smart home refers to discreet illness and trouble prevention and monitoring of residents who may not receive other forms of home care, such as the disabled or elderly [1].

The smart home concept is a promising and cost-effective way of improving access to home care for the elderly and disabled. Smart homes can be classified according to the types of equipment and systems installed. The major targets are improving comfort, dealing with medical rehabilitation, monitoring mobility and physiological parameters, and delivering therapy [2]. They can implement medication dispensing devices in order to ensure that necessary medications are taken at appropriate times

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[3]. Smart homes contribute to the support of the elderly, people with chronic illness and disabled people living alone at home. This new mode of health assessment can improve the quality and variety of information transmitted to the clinician. Measures of physiological signs and behavioral patterns can be translated into accurate predictors of health risk, even at an early stage, and can be combined with alarm-triggering systems as a technical platform to initiate appropriate action [5]. Another important advantage of the smart homes is that they allow the elderly and disabled to stay in their homes instead of moving to a costly health care facility. The transition to a health care facility can cause a lot of anxiety and home automation can either prevent or delay this anxiety [4].

Home automation sensor and actuators are the main building blocks in smart homes. The common home automation devices used in the smart home are lighting sensors, motion sensors, video cameras, gas and fire detectors, automated timers, automated doors and windows, chair and bed sensors, and also some more sophisticated systems, like remote keyless entry systems. Home automation systems may be used not only to provide security, entertainment, and energy conservation, but also to make it possible for the elderly and disabled to stay at their home, by providing an activity monitoring services. Home automation systems may include automatic reminder systems for the elderly [3].

This paper presents a novel concept for health monitoring systems such as elderly telehomecare and activity monitoring systems.

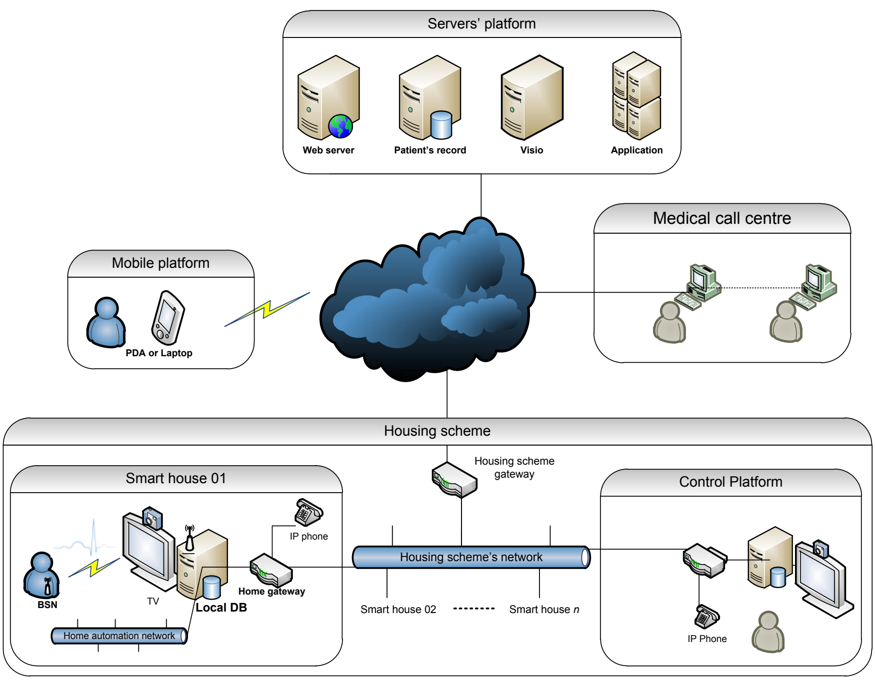

Fig. 1. "Maisons Vill'Âge®"

2 Maisons Vill'Âge®

Many telehomecare systems can be found in the literature [6-10]; however, it is difficult to find the system that matches exactly the end-user requirements. The analysis of the currently available solutions and ongoing projects motivated us to design a new concept of smart homes for the senior citizens, named in French "Maisons Vill'Âge®" (figure 1), is offered. This concept is a housing scheme with 25 to 50 dwelling units, organized as public or private divided co-ownership of immovable for seniors or retired person. Each housing scheme has a control unit. The administrator of the housing scheme uses this unit to monitor the hardware and software infrastructure.

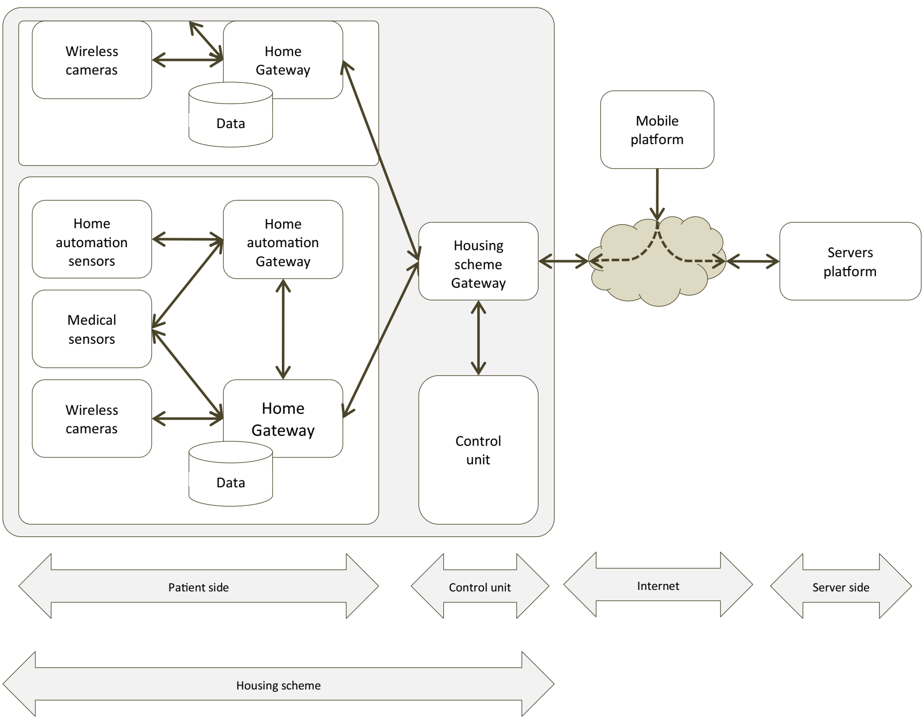

Fig. 2. Maisons Vill'Âge® architecture

Figure 2 shows the architecture of the system. The elements of this architecture are:

- Medical Sensors network (and/or Body Sensor Network (BSN)): This part consists of the medical instrumentation important to patients medical monitoring. This network consists of very small portable devices equipped with a variety of sensors for biological monitoring, patient localization and identification.
- Environmental Sensors and Home automation sensors network: This network must include sensors unfolded in environment (rooms, halls, WC …). These sensors can include those of the temperature, humidity, movement, acoustics, bed and chair sensors, etc.

- Wireless cameras network: this network is used for fall detection and for confirming the detection of anomalies.
- Home automation gateway: to communication with home automation sensors. The information of the sensors in this gateway is used also to activity monitoring in the Home Gateway.
- Home Gateway: It is a mini PC installed in each home. It connects body sensor network and also environmental sensors like home automation sensors and actuators to the Internet. It also includes intermediate receivers, assuring an efficient data transmission. In this gateway we do some preprocessing of the data received from medical and home automation sensors, to detect urgency anomalies.
- Mobile platform: this is a PDA or a laptop computer to receive the alerts and message by a professional, or to connect to server platform and view the patient's record. This platform can be used by persons to remote control his/her home.
- Server platform: consists of the different servers like: medical record, application, videoconference and web servers.

3 Discussion

An important point considered in developing this concept is QoS (Quality of Service) requirements, like availability and response time. As the healthcare industry is turning to information technology to help solve its business issues, specially provide to quality patient care services, it is important to develop QoS specification in distributed health information systems [11].

Any failure or lack of performance on the system which could not be tackled in a reasonable delay may have some damageable consequences on the solutions' acceptance and development potential: the confidence is a basic and elementary factor of acceptance or reject, such incident could also generate a psychological defiance towards ICT's in general and towards such innovative assistance and monitoring services.

For these raisons and for providing real-time data collecting, we developed a context-aware middleware [12] to give a dynamic and intelligent QoS to the system. It provides context data and takes into account QoS requirements of the applications. Measurements on a test bed have been carried out showing the good performance of our design. This context-aware middleware is a bridge between the healthcare applications and the sensor networks, to guarantee QoS needs, for supervision of the system and for easy configuration and installation of the sensor and actuators.

4 Conclusion

Given the high cost of activity monitoring systems and the efficiency of the home automation systems to provide the information about activities of the person, and also their efficiency for economize the energy consumption; we designed a system for elderly telehomecare and activity monitoring. In order to perform real-time information about activity level of the persons, the system uses home automation sensors and other environmental sensors like bed and chair sensors. The system has potential to increase independence and quality of life of elderly. This would not only benefit the elderly who wish to spend their old age in their own home, but also the national health care system by cutting costs significantly. By using this system, a new concept of smart homes for the senior citizens is offered, named in French "Maisons Vill'Âge®". The first housing schemes are being built in 2 departments of France.

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Pervasive Intelligence System to Enable Safety and Assistance in Kitchen for Home-Alone Elderly

Aung Aung Phyo Wai[1], Sivasubramaniam Shanthini Devi[2], Jit Biswas[1], and Sanjib Kumar Panda[2]

[1] Institute for Infocomm Research, 1 Fusionopolis Way, #21-01 Connexis, Singapore 138632
{apwaung,biswas}@i2r.a-star.edu.sg
[2] National University of Singapore, 21 Lower Kent Ridge Road, Singapore 119077
{shanshini,eleskp}@nus.edu.sg

Abstract. With growing aging population, elderly with physical or cognitive impairments may end up staying alone at home. Kitchen is generally the most vulnerable place at home as mishandling of devices or improper kitchen activities could lead to hazardous and life threatening situations. In this paper, we have proposed pervasive intelligence system that augment existing kitchen environment with sensors, actuators and processing intelligence. We have first identified possible safety issues and, then deploy sensors to recognize what happened and actuators to control kitchen settings. We have developed 3-stage processing with hierarchical inference approach to determine abnormalities in the kitchen. According to the severity of abnormalities, the proper appliances control or reminder escalation to appropriate personal will be issued to alleviate or minimize the undesirable consequences.

Keywords: home-alone elderly, kitchen, safety, pervasive intelligence system.

1 Introduction

Similar to graying demographic in the rest of the world, aging population has grown dramatically but support of those elderly by working adults has declined in Singapore. So, most of the elderly are forced to stay alone at home without proper assistance. The real problem here is when people grow older; they may suffer possible physical and cognitive deficits and face challenges to sustain living independently. At home, kitchen is the most dangerous and hazardous prone area while elderly is using kitchen alone. As such, it is necessary to develop a pervasive solution that can intelligently detect and prevent possible dangerous and hazardous conditions in the kitchen.

Although several works aimed to enable assistance to elderly at home [1][2][3], there are still limitations in adopting technology for home-alone elderly. In order to preserve safety and provide assistance, it is important not only to monitor resident activities and environment contexts [4] but also to control appliances usage [5][6].

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But none of previous works showed how to transform ordinary kitchen into intelligent setting embedding networked sensors and actuators.

In this paper, we have presented the design and development of pervasive intelligent system to support safety and well-being of the home-alone elderly in the kitchen. We identify issues related to safety in the kitchen and, design of kitchen environment with sensors to recognize what happened and actuators to control kitchen appliances in section 2. In section 3, we discuss details of intelligent processing approaches to detect abnormalities in the kitchen. We also discuss prototype setup, scenario and future works in section 4.

2 Safe and Assistance Kitchen for Home-Alone Elderly

In our scenario, the kitchen can be divided into four zones: medication and utensils, cooking, washing and appliances zones. Possible safety and well-being problems considered include forgetting to take medicines, turning on stove over long period, without closing water tap, etc. Depending on severity of safety situations, appropriate interventions such as turn off appliances or send reminders will be commenced.

2.1 Safety Application Scenarios in Kitchen

This is the scenario we consider to design and develop the intelligent kitchen settings. When elderly is entered into or leaved from the kitchen, combination of reed switch, pressure and motion sensor detect them. In medication zone, elderly will need to go in front of medication dispenser and take medicines that were automatically dispensed by dispenser at scheduled time. Then, elderly may take out utensils from drawers to prepare breakfast or lunch accordingly. In appliance zone, elderly open the fridge to take out food and then place them inside the microwave to cook or reheat the food ready for eating. A combination of reed switch and RFID enables to determine how elderly interact with appliances and which food they will be consuming. By monitoring the current drawn by active appliance by current sensors, the appliance operating time can be known and necessary appliance controls can also be done. The use of ultrasonic sensor enables to monitor whether the stove turned on without placing pot on the stove. Different temperature sensors at cooking zone ensure to detect cooking duration and infer fire hazardous [4] reliably. Moreover, sound impact sensor is used to classify water running out from tap and washing of dishes.

2.2 Intelligent System Design and Architecture

Based on designed kitchen scenarios with deployed sensors and actuators, intelligent kitchen system can be designed as shown in Fig. 1. The management layer is main intelligent component to determine the safety and hazardous conditions inside the kitchen. The platform layer includes Phidget SBC, interface kits and controller [7] to manage sensors and actuators deployed in the kitchen. It also uses X-10 protocol to control appliances in case of potential hazardous situations faced with appliances.

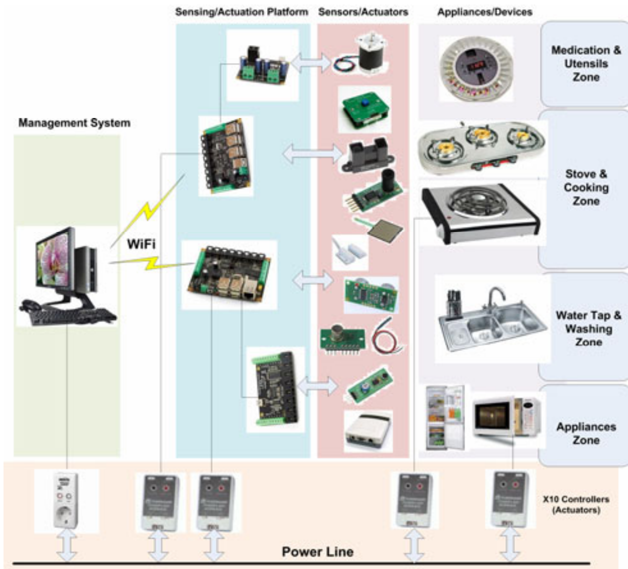

Fig. 1. Layered system architecture designed for intelligent kitchen environment

3 Proposed Methodologies for Intelligent Kitchen

In order to deal with uncertainty in abnormalities detection, we adopted possibility approach [8] with 3-stage processing framework. This approach resembles to human-like reasoning and has simplicity in handling multimodal inputs. The first stage is responsible to translate raw sensor outputs into fuzzy sets that represent sensor states and events according to relevant fuzzy membership functions [3]. The outputs from first stage are fuzzy sets that represent individual states and events detected by sensors and appliance states by corresponding fuzzy membership functions.

Fig. 2. Three-stage data processing methodology designed for intelligent kitchen system

The second stage combines fuzzy sets from individual sensors and actuators at stage one according to respective zones or user actions through DFA and fuzzy rules evaluation. Its outputs are the combined fuzzy sets of individual environment and user states. The final stage infers the possible abnormality in user activities as well as hazardous or dangerous situations of environment. It uses both recognized fuzzy sets from second stage as well as fuzzy sets representing three time intervals such as short, medium and long duration associated to user and environment states as shown in

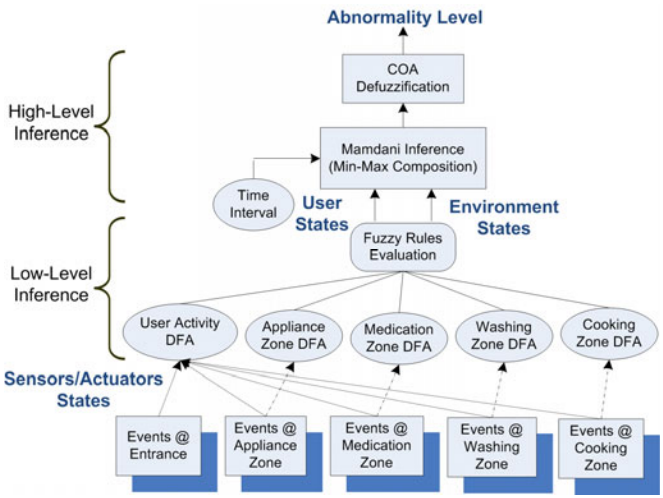

Fig. 3. Hierarchical inference proposed for recognizing abnormalities in the kitchen

Fig. 3. Depending on the severity of safety violations, appropriate interventions will be escalated such as controlling appliances or issuing reminders to elderly or care givers.

At low-level inference, current state of the zone was identified through combined events detected by sensors according to specified DFA. Finally, the fuzzified environment states at particular zones are inferred via fuzzy rule evaluation. The states and events from sensors correlated to user activities will be fused with approach similar to environment states evaluation to determine user states. By taking time interval fuzzy sets in association with zone and user states as inputs, high-level inference applies to infer the possible hazardous and dangerous situations with Mamdani inference [3]. Finally, defuzzification of fused fuzzy sets will be performed with Centroid Of Area (COA) method to infer the current abnormality level of safety, hazardous and dangerous situations related to both user and environment.

4 Discussion and Future Works

As a first step, we setup an intelligent kitchen prototype at our lab and a set of experiments will be conducted to evaluate the proposed intelligent approach. From ongoing experimentations, we will learn requirements and limitations to further improve and validate our proposed solution. For user activity recognition, we consider only simple and sequential high-level activities inside the kitchen rather than dealing with composite and interleaved low-level activities. Moreover, determining current location of elderly rely heavily on individual range sensors deployed at each zone. This will not be applicable in real settings due to possible clutters in environment as well as cost factors. A flexible precise and robust indoor location tracking technology is highly desirable. In data fusion approach, spatial contexts and temporal state transitions are processed separately instead of direct fusion of spatio-temporal sensor contexts. Upon successful outcomes, we will evaluate our solution at real home environment in future with test subjects studying more on its capability and usability aspects. Moreover, we are also planning to adapt current inference intelligence to meet varying user needs, environment dynamic and behaviors of the residents.

5 Conclusion

There have been growing demands and promising advancements that enables safety and well-being of the elderly through pervasive technologies. In this paper, we considered issues related to safety and well-being of the home-alone elderly in the kitchen. We have presented how to augment normal kitchen environment with proposed pervasive sensing and control architecture. Also, we have designed hierarchical inference methodologies from multimodal sensors to reliably infer the abnormality and hazardous conditions of the elderly as well as environment. We are hoping that our solution will bring beneficial to home-alone elderly who can continue their activities independently at kitchen while safeguarding safety at the same time.

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Heterogeneous Multi-sensor Fusion Based on an Evidential Network for Fall Detection

Paulo Armando Cavalcante Aguilar[1], Jerome Boudy[1], Dan Istrate[2], Hamid Medjahed[2], Bernadette Dorizzi[1], João Cesar Moura Mota[3], Jean Louis Baldinger[1], Toufik Guettari[1], and Imad Belfeki[1]

[1] Télécom SudParis, Electronic and Physic department, Evry France
[2] ESIGETEL, Avon, France
[3] Federal University of Ceara, Fortaleza, Brazil

{paulo.cavalcante,jerome.boudy,bernadette.dorizzi, jean-louis.baldinger,toufik.guettari, imad.belfeki}@it-sudparis.eu, {dan.istrate,hamid.medjahed}@esigetel.fr, mota@gtel.ufc.br

Abstract. The multi-sensor fusion can provide more accurate and reliable information compared to information from each sensor separately taken. Moreover, the data from multiple heterogeneous sensors present in the medical surveillance systems have different degrees of uncertainty. Among multi-sensor data fusion techniques, Bayesian methods and evidence theories such as Dempster-Shafer Theory (DST), are commonly used to handle the degree of uncertainty in the fusion processes. Based on a graphic representation of the DST called evidential networks, we propose a structure of heterogeneous multi-sensor fusion for falls detection. The proposed Evidential Network (EN) can handle the uncertainty present in a mobile and a fixed sensor-based remote monitoring systems (fall detection) by fusing them and therefore increasing the fall detection sensitivity compared to the a separated alone system.

Keywords: Remote medical monitoring, fall detection, Dempster Shafer Theory, Evidential Network.

1 Introduction

It is well known that multi-sensor fusion can provide more accurate and reliable information to detect distress situation for elderly persons living in their home. The data from multiple heterogeneous sensors of the medical surveillance systems present varying degrees of uncertainty and confidence [3]. Among multi-sensor fusion techniques, we can find Bayesian methods [1] and the Theory of Evidences based on the Dempster-Shafer theory (DST) [2-4, 9], which are commonly used to process and estimate degrees of uncertainty in the fusion process [4]. These theories are based on graphical representations: Bayesian Networks [1] and Evidential Networks (EN) [3,4,9].

This article investigates and implements an evidential network to detect fall situations and estimate its uncertainty degree through a heterogeneous multi-sensors fusion [3]. This network is indeed appropriate because, on one side, it prevents unreliable

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statistical model estimation due to the current lack of falls databases, and on the other side, knowing its property allowing to process heterogeneous classifiers or sensors output and to implement direct inference mechanisms on input observations such as actimetric data (body's movement, inclination) and vital data (cardiac frequency and fall index). The Evidential Networks are acyclic-directed graphs similar to Bayesian networks, but they use belief functions instead of probability functions. They are designed to handle uncertainty through the Dempster-Shafer Theory formalism.

In the following, first section 2 describes the remote medical monitoring platform constituting our targeted application, section 3 develops the Evidential Network application to the remote medical monitoring context by explaining how we implement the network and estimate the belief degree of a detected distress event such as hard or soft falls. Finally section 4 provides provisional evaluation results and section 5 concludes on this work with perspectives.

2 Remote Medical Monitoring Platform

A remote medical patient's monitoring system with alarm management [9], if integrated in a smart home environment, may use the result of several observation data fusion such as actimetric and vital signals captured by a device worn by the patient, external sensors such as acoustic and presence signals. Such a remote monitoring platform exists at Telecom SudParis elaborated with the close collaboration of Esigetel [8] and U558-INSERM (F. Steenkeste [6]). This Alarm management platform is composed of three detection sub-systems or modalities: GARDIEN [6, 5], RFPAT [7, 5] and ANASON [8]. In this new application work on Evidential Network, we first focused on two of these modalities: GARDIEN and RFPAT.

RFPAT system [7, 5] was designed for remote monitoring of vital and actimetric signals recorded on the person. This system can automatically identify distress situations such as falls, abrupt changes of cardiac rhythms (namely bradycardia trend) or person's activity (movements and lying down or standing posture). The GARDIEN system [6, 5] consists of a network of wired or wireless infrared motion sensors placed within the smart home environment. These sensors are activated by the body movements which indicate the presence of a person in the area of interest. The person's posture inclination can also be estimated from the combination of two types of infrared sensors, one for horizontal detection field, the other vertical [6].

3 Heterogeneous Multi-sensors Fusion for Fall Detection

Remote monitoring systems with alarm management (RFPAT and GARDIEN) studied in this work constitute complementary information and their fusion can provide more reliable detection compared to systems used separately. RFPAT modality is already a fall detector and the purpose of this fusion is to secure the detection of falls difficult to identify such as soft falls or falls without impacts on the ground. Contextual information, such as the person's localization and interaction with the environment are very useful and should be interpreted as complementary information by the fusion process. Evidential Network is indeed appropriate to our context because one can avoid the problem of unreliable statistical model estimation due to the current lack of distress events data (in our case falls). Moreover Evidential Networks present a very interesting property allowing to combine heterogeneous classifiers or/and sensors processing; they also permit to implement direct inference mechanisms on input observations such as actimetric data (body's movement, inclination) and vital data (cardiac frequency and fall index).

Based on the works of Lee, Hong and Nugent [3, 4], who proposed an Evidential Network for the recognition of activities in environments such as smart homes, we propose in this work an Evidential Network for activities inference such as fall detection as shown in Figure 1. The proposed fusion approach is based on the use of the Dempster-Shafer Theory operations and rules [2-4, 9] applied to vital, actimetric and contextual information extracted from the multimodal heterogeneous alarm management system previously described in Section 2. Binary data at lower-level (IR sensors) and at higher-level (from RFPAT) constitute the input "evidences" of the considered network.

This network is structured as an acyclic graph. Hierarchy and links between nodes create dependencies between the different alarm management modalities (GARDIEN and RFPAT), which makes the fusion process more robust and reliable for abnormal

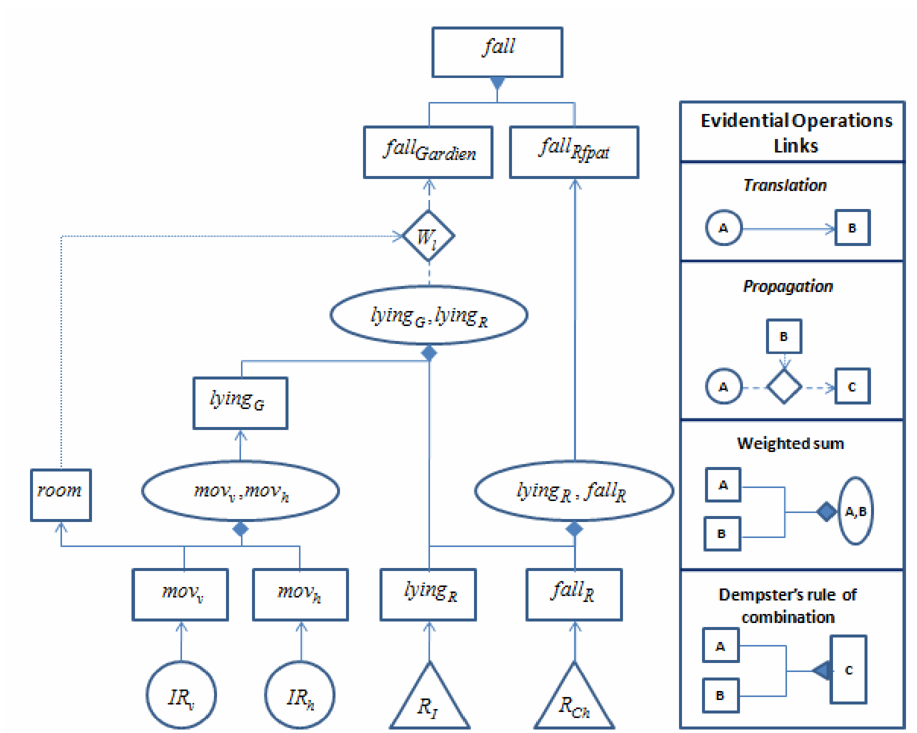

Fig. 1. Clearly the proposed network inference activities fall of person (left side). Connections between nodes represented by evidential operations (right).

events detections. In this network (Fig. 1), the circular nodes represent the GARDIEN IR sensors: vertical "IR_v" and horizontal "IR_h" fields IR sensors. The triangular nodes represent the RFPAT outputs: lying down or standing posture ("R_l") and fall ("R_{Ch}"). The square nodes represent contextual information the person's location itself ("rooms"). The rectangular nodes represent the person's activities: movement ("*mov*"), posture ("*lying*") and fall ("*fall*"). The connections between nodes are represented by evidential operations [3, 4, 9], as shown in the Table on the right side of Fig. 1.

3.2 Activity Inference of Evidential Networks

When starting the inference process of the evidential network, we assign Belief distributions to the input nodes based on a priori sensitivity and specificity information provided by the sensors (e.g. GARDIEN) and detection devices (e.g. RFPAT) developers. Evidential operations [3, 4, 9] are used in the propagation process of inputs evidences towards the top nodes layer of the network providing the Fall decision. Each Alarm processing modality can infer a Fall status Belief, denoted $m(\{Chute\})$, a Normal status Belief, $m(\{\neg Chute\})$, or uncertainty degree denoted $m(\{Chute, \neg Chute\})$. Then the overall mass functions are fused using the combination rule of Dempster-Shafer [2-4, 9] to reach a consensus decision. Based on [3, 4], the full development of our inference process is detailed in [9].

4 Preliminary Research Results

The evaluation of the proposed method was performed on data recorded at Telecom SudParis. These databases consist of 5 normal and 33 fall simulated scenarios containing 16 classical falls (rather violent) and 17 soft falls (with low acceleration). The purpose of our Evidential Network-based fusion system is to detect in very specific case of soft falls.

These databases are then used to evaluate the proposed Evidential Network. To this aim a confusion matrix has been computed on normal and fall situations to evaluate the Evidential Network performance, as shown in Table 1.

Table 1. Confusion matrix of the EN fusion

Confusion matrix		**EN fusion**	
		Normal	**Fall**
Scenarios	**Normal**	5	0
	Fall	2	31

In Table 1, the EN fusion has not detected only 2 fall cases which the network is not adapted. The EN fusion presented promising good performance (sensitive of 93,94%), in particular for soft fall cases, compared to separated modalities. The values of alone RFPAT system performance are not communicated for reasons of confidentiality due to a patent process underway. Furthermore we need to evaluate our system on a more extended database to confirm the contribution of EN fusion to the difficult falls to detect.

5 Conclusion and Perspectives

Evidential Network fusion of GARDIEN and RFPAT remote monitoring modalities improved the global fall detection sensitivity with regard to separate use of the two modalities: indeed the first conducted experiments have shown good fall detection performance, which also demonstrated the interest to perform a multimodal fusion, but we still need to evaluate this approach on more extended databases reflecting more cases of users. Moreover such an evidential network is modular and can detect falls even if the RFPAT system is not present in the fusion process. For future work we propose an extension of EN to the inference of various distress situations by adding more contextual information and parameters such as pulse rate, activity, abnormal sounds, in order to better represent the occurring distress situations.

Acknowledgment

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Cognitive Remediation for Inpatients with Schizophrenia or Schizoaffective Disorder Using "Smart" Technology in a Simulated Apartment: A Feasibility and Exploratory Study

Deborah Corring[1,3], Robbie Campbell[2,3], and Abraham Rudnick[2,3]

[1] The Faculty of Health Sciences, The University of Western Ontario
[2] Department of Psychiatry, The University of Western Ontario
[3] Regional Mental Health Care, St. Joseph's Health Care

Abstract. This study aimed to examine the feasibility of using and evaluating SMART (Supported Mental Assessment, Rehabilitation and Treatment) electronic technology as part of providing cognitive remediation for tertiary mental health care in-patients diagnosed with schizophrenia-related cognitive impairments that are considered a barrier to their independent living. This was an uncontrolled intervention feasibility and exploratory study. The study involved eight participants in total. Both qualitative and quantitative research strategies were used. Results to date are promising. Participating patients expressed satisfaction with the simulated apartment and the smart technology and patients were able to learn and use skills relevant to independent living.

Keywords: schizophrenia, cognition, smart technology.

1 Introduction

Individuals with schizophrenia-related disorders commonly experience ongoing and significant psychiatric disabilities related to cognitive impairments [1]. Some important functional disruptions associated with these cognitive impairments are unemployment, poor social skills, difficulties with achieving independent living skills and lack of adherence to medication regimes [1, 2]. Several key domains of cognitive impairment have been identified as important to address in persons with schizophrenia-related disorders. These include working memory, attention/vigilance, verbal learning and memory, visual learning and memory, reasoning and problem solving, speed of processing, and social cognition [4].

Cognitive remediation (restoration and compensation) for persons with schizophrenia has demonstrated improvements in relation to these domains of cognitive impairments [5], as well as in relation to functional outcomes such as employment [6-8].

"Smart" technology, i.e., interactive electronic and computer devices, has been used for other patient populations with cognitive impairments, e.g., elderly persons with primary cognitive impairments such as dementia [9], to assist them with daily functioning in-vivo, e.g., by visual and auditory prompts and cues in their living environments.

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There has been no systematic research to date on applying "smart" technology to the cognitive remediation of individuals with schizophrenia-related cognitive impairments. Stip et al [10], after reviewing the literature on cognition, remediation, smart homes and related technologies, concluded that rehabilitation of persons with schizophrenia and related cognitive deficits could be enhanced using smart home technology. We aimed to examine "smart" technology as applied to cognitive remediation with a severely psychiatrically disabled group of individuals, i.e., tertiary mental health care in-patients with schizophrenia or schizoaffective disorder, in order to facilitate their community integration through support for independent living

2 Methods

A convenience sample of 8 patients with schizophrenia or schizoaffective disorder and with reported difficulty in independent living participated in (up to) one month of cognitive remediation using SMART (electronic) technology in a simulated apartment at a tertiary care mental health centre. Evaluation consisted of baseline and end-of-intervention measures, including cognitive testing, semi-structured interviews at end-of-intervention with participating patients, and focus groups with involved clinical staff. Demographic, clinical and length of stay data was analyzed using descriptive statistics such as mean/median, standard deviation and percentage. Quantitative data was analyzed using the Wilcoxon signed ranks test for pre-post comparisons [11]. Qualitative data will undergo coding and thematic analysis [12]. Trustworthiness strategies will include triangulation, of interview and focus group data, and peer debriefing.

In-patients lived for up to one month in the simulated apartment, participating daily living activities - cooking, cleaning, socializing, and more, in preparation for discharge from the hospital. The patients received psychiatric care, occupational therapy, and other care as usual, and in addition used smart technology (two video-linked computers, one in the patient's apartment and one in the unit nursing station) which staff employed to "checked-in" with patients several times each day to inquire about wellbeing and monitor and prompt for daily living activities.

3 Results

Results to date are promising. Participating patients expressed satisfaction with the simulated apartment and the smart technology. Patients were able to learn and use skills relevant to independent living.

3.1 Qualitative Data

The qualitative data revealed three major themes. The following quotes illustrate these results from the patient and staff perspective.

The Apartment Experience

Benefits.

Participant 1- *I enjoyed it very, very much…I like to do my own cooking and uh, my own laundry. Cleaning was a little bit harder…I liked having my own telephone…having my* *own food. I wasn't sure if I had enough, what was going to last me how many days. I liked to go around singing by myself. It was much safer than on the unit. I knew that if somebody comes, I can lock the door. I can have a life in the apartment.*

Drawbacks.

Staff member- *the common [problem] was not being able to go out to their apartments and not having access to the smart technology after.*

The Technology

Benefits.

Participant 6- *I'm not too familiar with computers, and this computer's really easy to use. And the staff know what I'm doing…get to know what I'm doing…and I don't really have to uh, be watched by the staff, it's just once a day that I check in. It just helped, it kinda helped me to keep on the right track in a, in a way.*

Challenges.

Staff Member- *Well, sometimes the issue that we're having right now is that the client's not there to answer the system when staff are calling. There's several days where we don't have that connection, because the client's not there[…] And when the system goes down, the issue is that our system people can't fix it.*

Learning to Live on my Own Again

Participant 6- *It won't be as scary…to try living on my own again…because I'm familiar with everything I need to do to live on my own. And I did it in a safe setting, where if I couldn't, I could always go back to the ward if I needed to, um, I know for sure I'm ready to get out of the hospital now.*

3.2 Quantitative Data

Due to small sample size, few of the quantitative measures of psychological and cognitive function reached statistical significance; however, trends in some of these measures indicate potential modest improvements in participants' well-being. The improvement trends were scattered throughout the measures (not all the subscales of the measures). It is possible that some of the improvements were masked at follow up by the fact that many participants were very disappointed and frustrated about not going directly into their apartments in the community following the apartment experience. Returning to in-patient unit living was a dramatic change for them.

4 Conclusion

As noted above the results are promising, with patients and staff overall viewing the use of smart technology within the simulated apartment setting as a positive experience. These learning's will shape plans for further studies with controlled designs, with larger samples, and use of the technology in community settings as well as the development of clinical interventions.

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Smart Diabetes Management System Based on Service Oriented Architecture

Wail M. Omar[1] and Modafar Ati[2]

[1] Faculty of Computing and Information Technology, Sohar University, Oman
w.omar@soharuni.edu.om
[2] College of Engineering and Computer Science, Abu Dhabi University, United Arab Emirates
Modafar.ati@adu.ac.ae

Abstract. Diabetes is one of the chronic diseases that have an effect on the life of a large number of people around the world. This chronic disease causes approximately 5% of all deaths globally each year[1], and is most likely to increase exponentially within the coming few years. Reduction to the effect of such a disease, a close monitoring to patients is essential in order to control its level via increasing patients' awareness. Thus a smart system that is capable of collecting medical readings from patients, analyzing the data, and suggesting the appropriate diagnosis has become a necessity. This work advises a system that is capable of meeting all of the above along with reducing the physical access load on healthcare centers via instructing the system to notify both healthcare provider and patients with the acquired results

Keywords: Controlling Diabetes, Monitoring Diabetes, E-Health, SOA, Grid Computing.

1 Introduction

The number of people who have been diagnosed as diabetes is too high, Statistics indicates that such a chronic disease causes approximately 5% of all deaths globally each year[1], which are likely to increase by more than 5% in the next 10 years in case no urgent action is taken.

In recent years, a pattern of chronic diseases start to emerge in the Middle East. These diseases appear in the form of increase in obesity, heart diseases, and diabetes. This increase in chronic illness along with the increase of sedentary lifestyle in the Middle East has imposed a great pressure on healthcare providers especially when trying to ensure that structured patient follow up is achieved after each therapeutic change.

United Arab Emirates, where this research is conducted, has its own share of chronic diseases. The percentage of people who have diabetes cases in the country is the second highest in the entire world. In a latest study that was conducted jointly by the World Health Organization and the Ministry of Health in the United Arab Emirates, where around 6,609 samples were investigated. These samples were further classified into national and expatriates. The samples were formed of 2,363 nationals and 4,246 expatriates. The overall percentage of people of diabetes was 19.6%. This

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percentage is distributed as 24% among nationals and 17.4% among expatriates, highlighting the higher prevalence in the native UAE population. Adding to that this percentage is proportional to the age of people. It is estimated that people suffering from diabetes over the age of 60 is around 40%. As a result, the Ministry of Health in the UAE set the priorities to draw a strategy that aims to increase people awareness as first step to control this chronic disease.

The purpose of this research is to create a model that is capable of predicting status of patient's condition. These conditions are driven from a number of factors that will be highlighted during the course of the paper. Furthermore, the current proposed model is considered as the bases for predicting other diseases as well as other services. Hence, SOA is used in order to accommodate these services in future work. Currently the system is capable of predicting diabetes cases only.

The paper is structured as background in section 2, followed by problem statement and model. Section 5 presents the expected scenario of using the proposed model. Evaluation to the model is presented in section 6. Conclusion is demonstrated in section 7.

2 Background

The advancement in communication and information technologies in recent years has gave the researchers an opportunity to use these technologies in order to resolve problems that are associated with managing and monitoring chronic disease patients. Omar *et al*[2-4] proposed a semantic framework that provides an intelligent remote health monitoring service via implementing a method of exchanging information between sensors and actuators in an open standard format. Where data can be collected via a request from the health provider as part of a structured patient follow up. This is along with the proposal from Black *et al*[5], where they proposed an automated remote monitoring system that involves patients proactively in the care of their condition by using spoken dialogue technology. However, the study was limited to only 5 patients. Furthermore, Benny *et al*[6] proposed the use of pervasive sensing technology and wireless communication in order to create the concept of Body Sensing Networks (BSN). However, the latter proposed system has not been implemented for chronic patients monitoring.

Bai*et al*[7] suggested the building of web-based services information system to aid the activities in diabetic healthcare. Two groups were recognized; healthcare receivers (patients) and various care providers. Mobile-network communication platform for homecare supervision used for preparation prior to face to face diagnoses. Web applications were also used for delivering worthwhile health care services to chronic diseases patients. These web applications were developed in order to support patients in self-managing their diabetes via monitoring their health as well as communicating with their healthcare providers[*8*].

3 Problem Statement

Diabetes and most of the chronic diseases normally requires a continuous attendance and follow up in order to make sure that factors affecting patients are at least within the normal threshold. Any variation of these factors requires measures that put in place to bring these factors to as near as possible to the accepted level. This continuous assessments would be extremely difficult, if not impossible, to be carried physically especially with the increase of number of patients that require such attention. Therefore, an urgent need for seeking for a new approach that helps in minimizing the pressure on healthcare centers is essential. One approach that can be adopted is via using ICT. By using such technology we propose a system that is able to collect the medical readings remotely according to either schedule time or on demand, save the readings in patient's profile (which is part of the Patient Health Record), analyze the data and then propose a feedback to patient as well as healthcare centers. Such system requires a model that is able to differentiate between different patients due to the fact that life readings are different. Thus, the system should be smart enough to propose the appropriate diagnose to the collected medical readings.

4 Model

The system consists of many services from different vendors. SOA is proposed in this research to offer the platform for deploying, discovering, and invoking these services. Omar *et al*[2, 4, 9] designed and developed an SOA model for healthcare applications. In their work, they proposed the merging of different technologies under SOA model, which are Web 2.0 and Grid Computing. This arrangement is given the acronym SOAW2G. Due to the fact that the latter arrangement offers a manageable framework that takes care of connecting the users with the resources, then SOAW2G would be very convenient and most appropriate for our research. The use of both Web2.0 and Grid Computing will offer the required services and resources to run the system. Figure 1 presents the SOAW2G model that consists of eight layers namely; Resources, Resources management, Control, Support functions, user interface, security, knowledge, management, and user layers.

The resource management layer (magnified in Figure 1) is responsible for classifying the resources that are deployed by the provider, according to the nature,

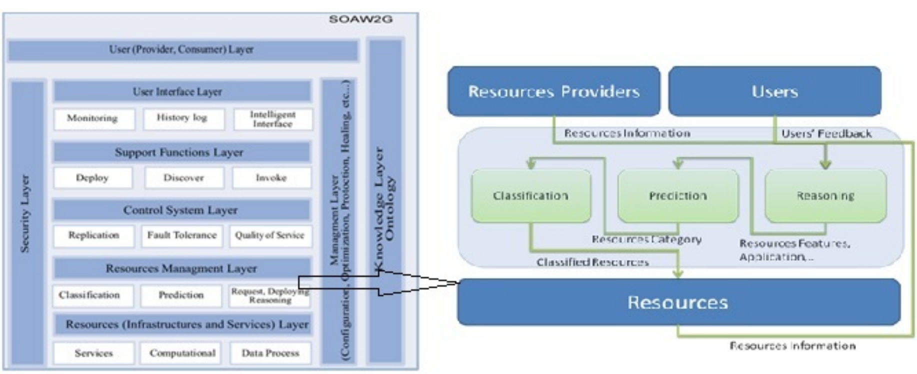

Fig. 1. SOAW2G model and Resource Management Layer

functionality and behavior of resources. Such a classification process has been proposed to improve the functionality of the underneath layer, by enhancing the manageability and fidelity of selecting resources. Users' feedback is used to improve the classification processes. This layer consist of three main components (as shown in Figure 1) to accomplish the task of classifying resources; reasoning, prediction and classification. Description to the rest of the layers along with their purposes is to be detailed in a separate paper.

5 Motivating Scenario

Prior to building the medical schema, the parameters that are required by health authorities in the UAE for diabetes patients should be identified. Following the identification stage, the skeleton model is then created and ready for the bulk of data to be imported. The parameters that are used in the medical schema (but not limited to) are; age, sex, history of heart disease, BMI, SBP, DBP,FBS, Hb1Ac, HDL, LDL, Trig, urea level, . . . etc. Following the creation of the skeleton model, the health providers provide archive data that are identical to that defined in the medical schema to be used for training, testing, and adjusting the model. At this stage the model would be ready for training which can be achieved via using one of the available techniques such as SVM, machine learning and data mining techniques. These techniques are usually used along with initial classifications and categorizations to the different cases that are provided as part of the training data. The quality and quantity of data contribute greatly to the adequacy of the operational system.

The smart chronic disease management system is an on demand system that reacts to the hospital's stipulate. This management system is usually instigated via issuing a request by the health provider to invoke the appropriate sensor that is located at the patient side to collect target data. The data received are inspected by the previously trained model in order to diagnose the case based on both the readings and the categorization method used to train the system at the initial stages. It then saves the results into the patient health record along with timestamp that serves for patient condition monitoring over a period of time. The system would then predict the outcome based on these data and inform both the patient and the health provider of the predicated condition. Figure 2 highlights the activities that are stated above.

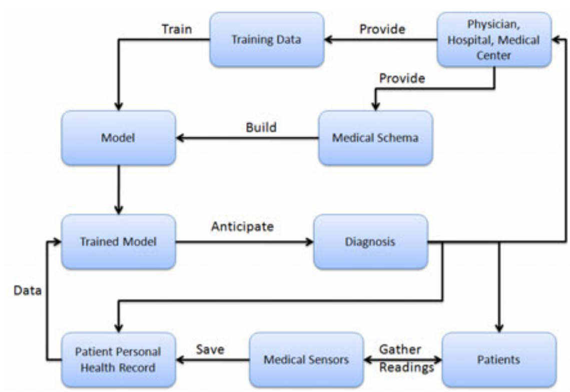

Fig. 2. System Scenario

6 Results and Discussions

The schema used in this research is based on the information that are collected by the health authority in the UAE. As such, the schema is divided into a number of main categories namely; risk factors, laboratory data, physical examination data, and chemistry examination data. Each category contains a certain number of factors, i.e laboratory data category contains data related to BMI, SBP, DBP, Duration, FBS, PPS, OHA, Insulin, . . etc. There are different techniques that can be used in machine learning that provide the system with the prediction process that is needed as part of the diagnosing process. However, Weka[10] is used within this work to generate the model and test different type of machine learning in order to find the most appropriate model for diagnosing diabetes. The listing below highlights some of the attributes and data that are used in the process of training the model. It must be stated that the last attribute as well the last data value of each patient's data refers to the diagnose for that patient. At the first stage physicians are usually derive this value based on the data attributes, which are then fed to Weka in order to train and test the system. Weka usually requires two inputs; one for training the system whiles the other contains the collected data (via sensor combined with those collected from the schema) without any diagnoses. With such arrangement, Weka would then predict any missing attribute that is not provided by the test data (in this case diagnosis).

```
% This is a dataset for Diabetes model
@ relation diabetes_data_July-2010
@attribute age real
@attribute gender{male, female}
@attribute Marital_Status{single, married, widow}
@attribute family_history_of_diabetes {Yes, No}
@attribute BMI real
@attribute Diagnose real
@data
42, male. married, yes, no, 20, 2, 17.52, 110, 70, 110, 70, 110.83, 1, 0, 0, 0, 0, 0,0, 0, 0, 381, 439, 0, 1, 0, 0, 0, 0, 4
54, female, married, yes, yes,66, 1, 20.96, 150, 90, 150, 90, 75.64, 22, 1, 0, 1, 1, 0, 29, 1, 1, 129, 322, 1, 1, 0, 1, 0, 0, 8
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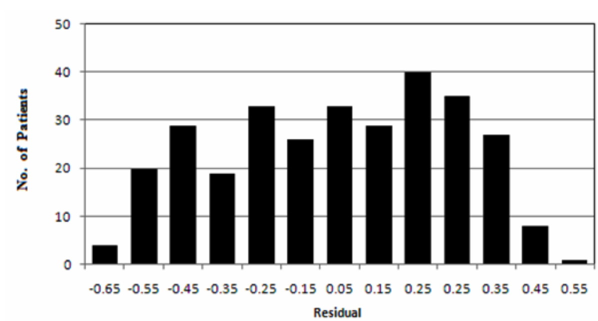

Fig. 3. No. of patients vs. residual

The diagnose attribute used in our model is represented as a numerical value between 1 and 10, where 1 indicates healthy patient while 10 indicates that the condition of the patient is critical and an urgent measures should be taken. The scale of 10 is selected to give more option to the system to classify monitored cases. Values between these two ends indicate different conditions ranges from being Very Good, Fair, and Very Bad. Following training the system, a total number of 304 patients were tested using the proposed system, figure 3 shows the residual between physician diagnose and that predicted by the system. It can be seen that majority of diagnose results lie between -0.55 and 0.45. Furthermore, 20.4% have been identical to that of physicians.

7 Conclusion

In this work a smart diabetes management system has been developed and is able to collect medical readings from diabetes patients. Data received are analyzed based on a proposed medical schema from the healthcare provider. Both patient and healthcare provider are notified of the condition of the patient following the collection and analyzing of data. Comparisons between physician's diagnoses and that produced by the system were demonstrated and the results shown were very promising. However, different techniques need to be tested in order to choose the most appropriate techniques that suit our model. At this stage, the model proposed here is adequate and can be implemented for diagnosing and monitoring patients in the region of interest.

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An Ambient Approach to Emergency Detection Based on Location Tracking

Martin Floeck, Lothar Litz, and Thorsten Rodner

University of Kaiserslautern, Faculty of Electrical and Computer Engineering, Institute of Automatic Control, 67663 Kaiserslautern, Germany
{floeck,litz,rodner}@eit.uni-kl.de

Abstract. In previous works overall activity and inactivity levels of users living in Ambient Assisted Living (AAL) enabled flats were determined using standard home automation sensors. The flats are regular dwellings for long-term use by approximately 30 tenants located in Kaiserslautern, Germany. In this real-world AAL project[1] it was shown that basic inactivity alarms based on linear thresholds can be triggered within 30 to 180 minutes after the occurrence of a potential emergency. However, inactivity alarms are somewhat coarse and do not make full use of additional information inherent in the raw sensor data: spatial and temporal information regarding the location of a tenant in their flat and the time spent in a room. Using that information, it can be determined in which room a tenant has resided for how long at a given time. Hence, in this paper a method for location tracking is proposed, forming a novel alarming criterion.

Keywords: Ambient Assisted Living, Activity Monitoring, Assistive Technology, Ambient Intelligence, Location Tracking.

1 Introduction

A real-world AAL project is currently being conducted in Kaiserslautern, Germany [1–3]. About 30 tenants are monitored in their flats with standard, off-the-shelf home automation sensors (motion detectors, door/window contacts, or light switches). Between 23 and 37 of such sensors –depending on the size of the flat– capture activity data forming the basis for activity and inactivity profiles of the tenants.

Ambient sensors offer a range of advantages: First, the willingness of future users to accept new AAL technologies is much better than in case of sensors worn on the body. Body-worn sensors are often regarded as stigmatising and thus rejected [4]. Second, ambient technology is far less intrusive than body-worn sensors (e.g., heart rate monitors). It is believed that even without collecting medical data, significant improvements of a person's safety in their private home can be achieved by means of inactivity monitoring and location tracking. Third, ambient technology offering added value for the tenant on top of health monitoring, e.g., comfort and safety, can already be used in an early stage long before the health aspect becomes the prime driver.

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2 Potential of the Ambient Sensor Approach

Several approaches for monitoring activity were published (e.g., [5, 6]) but to the best of the authors' knowledge few solutions for automatic alarming are readily available.

In the authors' previous works, sensor data had only been evaluated in its entirety. E.g., no single sensor is capable of sensing global activity or inactivity in a flat. This knowledge can only be obtained by combining signals from all sensors in a flat. In this paper, Mealy finite state machines (FSMs) are run on sequences of sensor telegrams received over time. By doing so, the following information can be obtained:

- *General activity/inactivity*
  By using an FSM whose input alphabet ***V*** is composed of the *active* and *inactive* telegrams from the various sensors, it can be determined whether there is any activity at all in the flat or whether there is global inactivity (see [1] for details).

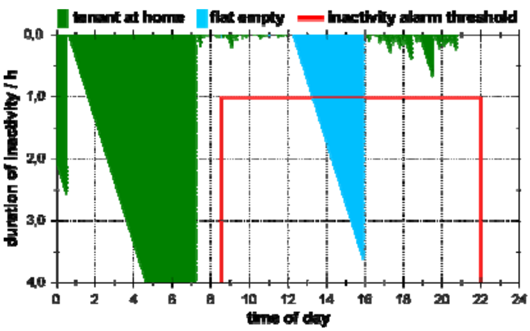

Fig. 1. Inactivity graph of one day (spikes) and inactivity alarm threshold (line)

In Fig. 1, the spikes indicate global inactivity. The duration of inactivity is continuously evaluated and an alarm is triggered if the duration of inactivity exceeds a set threshold. In practice this can for example mean an emergency call centre is contacted if inactivity of more than one hour is observed. Alarm thresholds of one to three hours proved to be well-suited. At night, alarming is disabled.

- *Is tenant is at home or is flat empty?*
  Alarms may on no account be raised erroneously when the flat is empty but the AAL system has no knowledge about this fact and thus assumes an emergency after extended inactivity due to the user being away. An FSM combining the sensor signals from the front door sensors and activity information from all other sensors produces the desired output (flat occupied/empty). Details can be found in [1].
- *Change of the activity/inactivity patterns of a tenant after an emergency*
  In case of a fall, there may still be activity captured by motion sensors if the tenant is not unconscious, i.e., activity will not cease but change its pattern. Thus, the user's mobility will most likely be restricted so that observed activity is confined to a single room or will move from one room to another very slowly at the most. Such a change in behaviour is easy to track (*"location tracking"*), constitutes an alarm criterion in itself, and will be addressed as the focal point of this paper below.

It is believed that, ultimately, a combination of several of the above alarm criteria will constitute the most viable approach to reliable health and emergency monitoring.

3 Location Tracking Using a Finite State Machine

It was shown in [1] that the typical durations of stay (*DoS*) of a tenant in the rooms of their flat follow patterns that are unique to each tenant. That is, the maximum *DoS's* differ significantly from room to room and tenant to tenant: The four graphs in Fig. 2 immediately show the actual location (room) of a tenant *A* and the *DoS* (Eq. 1) spent there during the day.

$$DoS\,(R,\,D,\,t) = \text{time elapsed since room change into current room} \tag{1}$$

where *R* is the room under consideration, *D* is the day, and *t* is the time of the day.

Times continuously spent in the sitting room and the bedroom are clearly visible whereas times in the bathroom and vestibule are one order of magnitude smaller and believed to be negligible. Tenant *A* exhibits considerable mobility since he seldom spent more than 20-30 minutes in the sitting room on end but entered the bedroom or vestibule for such short times that they hardly become discernible in the diagram.

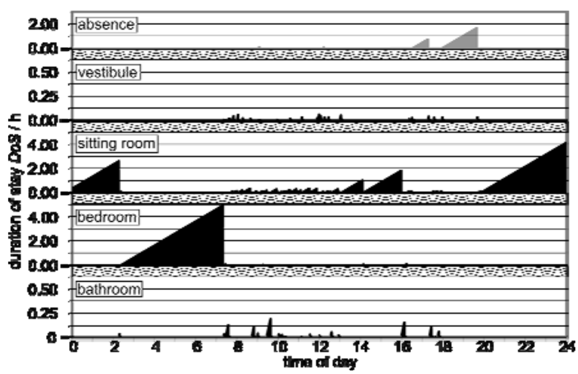

Fig. 2. Location of tenant A throughout the day and duration of stay (*DoS*)

The tenant's location is tracked using the tracking FSM in Fig. 3. It has been simplified since introducing the original FSM is beyond the scope of this paper (see [1] for details). In essence, only the motion detectors are considered for tracking since all other home automation components can remotely be controlled from a central control unit. I.e., the lights in a room, for example, can be switched without the tenant being in that room. By also evaluating the state of the presence FSM, absence can also be accommodated, i.e., the time a person spends outside their flat will not be allotted to any room but the category "absence".

Evaluating a single day only, however, does not allow drawing valid conclusions as to where a person typically spends their time since one day is not representative of someone's daily routine. By evaluating a tenant's location over multiple days, the likelihood of him being in a particular room at a given time can be learned during the training period. Matching the actual location of the tenant with the learned probability of being there allows classifying whether or not the user is in an expected location and –if not– for how long the unexpected situation has already existed.

This learning approach will be illustrated using data of 21 days captured in the flat of tenant *B*. The *DoS* for every room on every of the 21 days was determined at an interval of 10 min. E.g., if the tenant enters the sitting room on day 1 at 1230, the *DoS*(*sitting room*, 1, 1240) would be 10 min. In Fig. 4, the number of times a *DoS* had been observed (number of occurrences *NO*) in the bathroom at a particular time of the day is plotted. The bin widths are given in the diagram; a *DoS* of 0 seconds means that the tenant is not present. Within that particular flat, the evaluation of the typical *DoS* in the various rooms revealed that the tenant hardly ever spends more than two hours in one room continuously without entering another room.

It turned out, for example, that the tenant sometimes spends an hour or more in the bathroom in the evening and that the tenant frequently gets up at night to use the

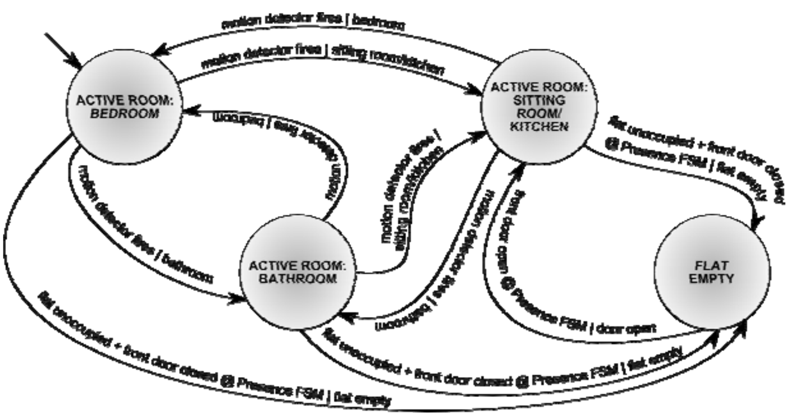

Fig. 3. Simplified FSM for user tracking. Transitions containing '@' utilise knowledge on states generated by the presence FSM.[2]

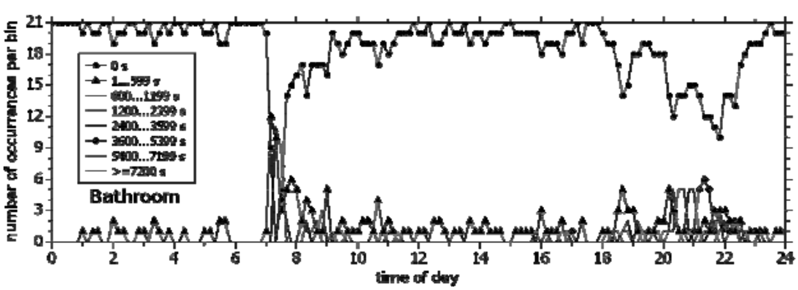

Fig. 4. Frequency distribution of the *DoS* of tenant B in the bathroom in steps of 10 minutes based on a data set from 21 days

[2] The vestibule has been omitted in this FSM for reasons of clarity and conciseness.

bathroom. The former finding can be put down to the tenant getting ready for bed. Moreover, it could be shown that the tenant very often is not in the sitting room[3] during the day. Data from the bedroom[3] match this finding in that the tenant spends a lot of time during the day in the bedroom working at their desk located there.

To be able to automatically raise alarms based on "training" data collected during the 21 days shown in Fig. 4, rules must be established that allow rating how likely it is that a *DoS* observed at a given time is critical. Thus, the *NO* of the *DoS's* shown in Fig. 4 were added up in step 1, yielding the accumulated number of occurrences NO_{acc} (Eq. 2). NO_{acc} is calculated as short *DoS's* are generally believed to be non-critical since they involve recent physical activity (i.e., moving from one room to another) which is regarded as an indicator for the tenant's well-being. In contrast to that, long *DoS's* indicate that there had been no movement from one room to another for a longer period of time. If long *DoS's* are observed at a given time but occurred never or only very few times in the training period, a potentially dangerous situation, e.g., a fall, cannot be excluded: The tenant might have fallen and is now lying on the floor.

$$NO_{acc}(R,\ t,\ DoS_{\min}) = |\{ DoS(\cdot) \mid DoS_{\min} < DoS(\cdot) \}| \tag{2}$$

where DoS_{min} is the minimum duration of stay to be considered for NO_{acc}.

In step 2, NO_{acc} is transformed into a probability $P(R, t, DoS_{min}, TP)$ indicating the likelihood of encountering a *DoS* of *x* or more minutes in a particular room (Eq. 3).

$$P(R,\ t,\ DoS_{\min},\ TP) = \frac{NO_{acc}(R,\ t,\ DoS_{\min})}{|TP|} \tag{3}$$

where *TP* is the set of days in the training period.

Fig. 5 shows the resulting probability diagram for the bathroom. $P(\text{presence} > 0\ \text{min})$ indicates how likely it is that the tenant is in the bathroom at different times of the day. It is given for informational purposes only – if $P(\text{presence} > 0\ \text{min})$ was used for alarming, false alarms would result every time the tenant enters a room at a time he had never done so during the training period.

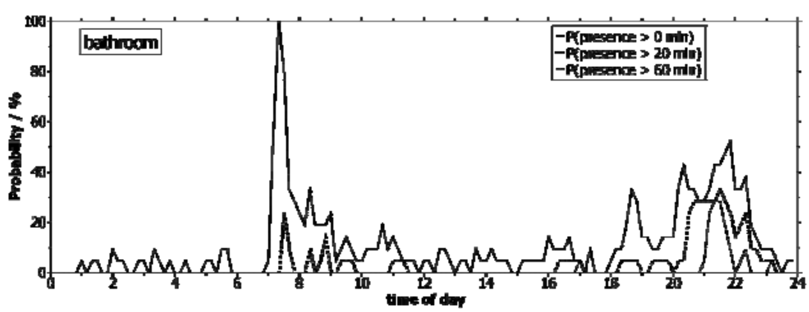

Fig. 5. Probability distribution of tenant B having spent more than *x* minutes in the bathroom

[3] No diagram shown here for space reasons.

The other two probability graphs for 20 and 60 minutes, however, are suitable for automatic alarming. There are two degrees of freedom in this alarming scheme: DoS_{min} and the threshold probability $P_{threshold}(DoS_{min})$. The *DoS's* of 20 and 60 minutes were chosen deliberately and are believed to be useful values. The threshold probability is the probability with which the tenant has to have spent at least DoS_{min} in a room and can also be chosen arbitrarily.

However, both DoS_{min} and $P_{threshold}(DoS_{min})$ were chosen based on an educated guess: The DoS_{min}*'s* of 20 and 60 minutes, respectively, were selected because Fig. 4 indicates that *DoS's* of more than 20 minutes only occur infrequently and thus may be a first indicator of potentially dangerous situations. In contrast to *DoS's* of 20 minutes, *DoS's* of more than 60 minutes can hardly ever be observed so that it is believed that exceeding this DoS_{min} is a more reliable indicator of potential emergencies. Setting the threshold probability $P_{threshold}(DoS_{min})$ to 5% is believed to be reasonable with regard to the data shown in the Fig. 5.

Based on the above reasoning, a set of alarm rules is ultimately established in step 3 to allow automatic alarming:

Rule 1	IF (0 min $\leq DoS(R, t) <$ 20 min)	THEN do not raise alarm & quit
Rule 2	ELSE IF (20 min $< DoS(R, t) <$ 60 min)	THEN
	IF ($P(R, t,$ 20 min, $TP) <$ 5%)	THEN raise alarm & quit
Rule 3	ELSE IF (60 min $< DoS(R, t)$)	THEN
	IF ($P(R, t,$ 60 min, $TP) <$ 5%)	THEN raise alarm & quit
Rule 4	ELSE quit	

4 Outlook

This alarming scheme is still under development. Test runs involving several tenants from two real-world AAL projects will be conducted in the near future to validate the fitness of –and, if necessary, to optimise– the current values for DoS_{min} and $P_{threshold}(DoS_{min})$. In the long run, additional research will be carried out to validate the preliminary experimental results discussed here and to ensure genericness and transferability of the AAL solutions presented above: The developed AAL environment shall be suitable for use by a large variety of users under many different conditions.

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A Study of Long Term Tendencies in Residents' Activities of Daily Living at a Group Home for People with Dementia Using RFID Slippers

Tsutomu Fujinami[1], Motoki Miura[2], Ryozo Takatsuka[1], and Taro Sugihara[1]

[1] Japan Advanced Institute of Science and Technology
[2] Kyushu Institute of Technology

Abstract. A growing number of the elderly with dementia are accommodated to group homes and live with caregivers in Japan. We are concerned with Activities of Daily Living(ADL) of these residents and installed into a group home a sensor network as a pilot study to record and analyze their whereabouts. Twenty one antennas were placed under mats and five residents wore slippers into which Radio Frequency IDentification(RFID) tags were inserted. We collected location data for thirty months and looked for long term tendencies in their activities. We found that the information concerning their whereabouts may indicate their waning health conditions and may reflect caregivers' treatment. We also found a seasonal effect on residents' mobilities, a decline in summer. The result shows that location data may be exploited as a valuable source to recognize residents' slowly changing conditions.

1 Introduction

Sensor networks at home are expected to ensure safety and security for residents, which are surely of prime importance. There also arises an interest to their well-being, which may be promoted with sensor networks although the notion needs to be refined for information technologies to be applied for.

A growing number of the elderly with dementia are accommodated to group homes and live with caregivers in Japan. The notion of Activities of Daily Living(ADL) suits to evaluate how well the residents live their lives at home, but no means is usually provided to caregivers to observe residents' activities except for their eyes. It is thus often difficult for them to notice long term tendencies of ADL as for each resident.

We employ RFID technologies to track residents' whereabouts. With the device, we can collect data automatically for a long time without bothering caregivers to record them. The question is, what items of knowledge we can extract of the data which may help caregivers to improve their work. We are especially concerned with long term tendencies observed in their ADL because they can be identified most effectively using information and communication technologies.

Some research projects pay attention to ADL of people with dementia[6]. They usually focus on a particular act such as washing hands[1] and develop a system

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to prompt the user to carry out a particular act[2,5]. We are however interested in the activities occurring in broader spatiotemporal settings. Some researchers employ RFID technologies to track subjects' behaviors[3], but they observe mice, not human. To our knowledge, there has been no long-term investigation into Activities of Daily Living at a Group Home, using RFID.

The paper is organized as follows: Section 2 describes how we collected data, Section 3 explicates what items of knowledge we extract of the data. The article is concluded with a summary and future prospects.

2 Data Collection

A group home in Japan kindly allowed us to collect data. The house was originally built about sixty years ago for a family and then was converted into a group home a decade ago to accommodate up to six people with dementia. These people live their lives in the care provided by caregivers. Two or three caregivers usually take care of them in the daytime and one caregiver at night.

We have installed into a group home twenty one antennas and asked the residents and caregivers to wear slippers into which RFID tags are inserted. As each slipper bears a unique identification, we can track residents' whereabouts when they step on one of these mats. The sensor network is used to notify caregivers of residents' moves at partiular places with a melody unique to each person, enabling them to know where each resident is even if he or she is out of their sights. The detail of the alarm system is described in one of our articles[4].

We have collected the data, their whereabouts, up to now since June 2008. We limit the time span to be considered to the period starting at 3rd June, 2008, and ending at 6th November, 2010, for the sake of analysis. The number of entries recording moves for all the persons wearing RFID slippers reached to 3,905,158 items for those thirty months. The number of entries for the five residents, whose data we examine below, is 1,946,264.

3 Analyses

To see long term tendencies of ADL in the pre-processed data, we divide the 128 weeks starting from 1st June, 2008, to 6th November, 2010, into 32 sections, each of which contains four weeks. We analyze the data in two respects: adherence and mobility. By adherence, we mean where each resident tends to stay. By mobility, we mean how often they move in the house.

3.1 Adherence

Fig. 1 depicts the time trends in terms of whereabouts as for the five residents A to E. Each bar denotes the total sum of the durations for the section for which the person is detected to stay at one of those mats. Each color represents a particular mat, whose correspondance is shown in the legend.

For the person A, there is a sudden change of colors at the time point 1, where the pink(6) is turned into yellow-green(5). Both pink(6) and yellow-green(5) are antennas at the table in the dining room, but in the opposite side with each other. The person B shows a similar change of places from pink(6) to yellow-green(5) at the time point 2. The person broke her leg at the time point and the graph depicts that she became to sit at 5, the side near to the kitchen after the accident.

The person C shows a stable trend with a mild peak in the middle. He seems to have increasingly spent most of his time in his room towards the end. The person D shows a relatively stable trend with a mild peak in the middle.

3.2 Mobility

Fig. 2 shows the time trends in terms of mobility as for each resident. Each bar represents the total time in which the person was moving from a particular place to another. Different colors indicate the sub-totals for different paths, combinations of two mats between which the person walked, but some paths are colored same as we cannot prepare for more than 400 colors to draw every path distinctively.

As for the person A, we recognize two peaks, one at the time point 1 and the other at the time point 2. The person B used to be the most active among the residents as long as we judge it based on the data. Her activities reached to the first peak around the time point 3 and became stable at time point 4 after a mild decline. The activity level was however drastically dropped at time point 5 after the accident, followed by a gradual decline.

The person C shows a stable trend with two peaks at time points 6 and 8 with a mild decline around the time point 7. The person D also shows a stable trend with a mild peak around time point 9. Her activiy dropped around time point 10, followed by a recovery up to time point 11. The person E was most active at time point 13 between time point 12 and 14.

Interesting to these graphs is that a seasonal effect is recognizable. Time points, t1, t2, and t3 denote August, the hottest month in Japan and the activity levels in summer dropped to the lowest for all the residents. The residents also seem to be most active in winter, but peaks are not so distinctive compared to those bottoms. A closer look reveals that causes are complex, i.e., not a single cause we can spot.

4 Conclusion

We collected location data at a group home from five residents for 30 months to analyze long term tendencies in their activities. There are some declines readable from their whereabouts, often suggesting a waning health condition or an accident. Caregivers seem to have guided each resident to sit in a particular place depending on her perceived condition. Those graphs in Fig. 1 reflect how they were treated by caregivers, too.

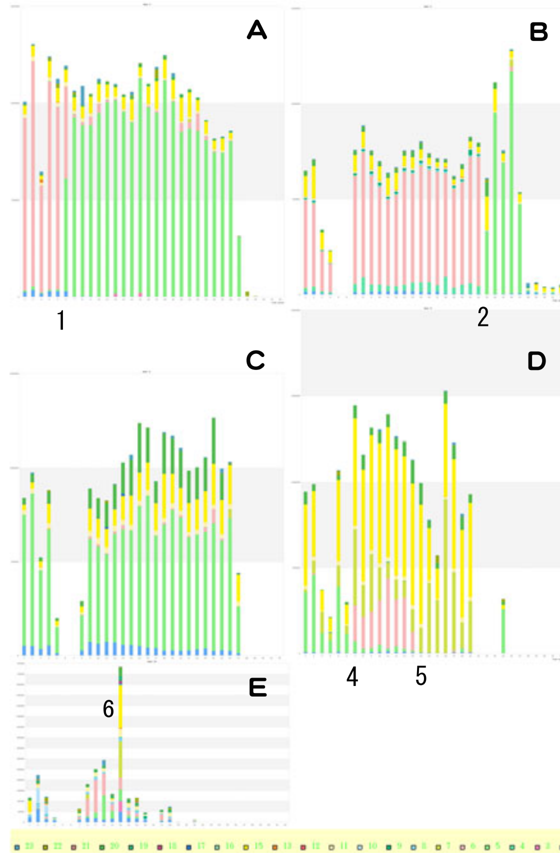

Fig. 1. Time Trends of Residents' Whereabouts

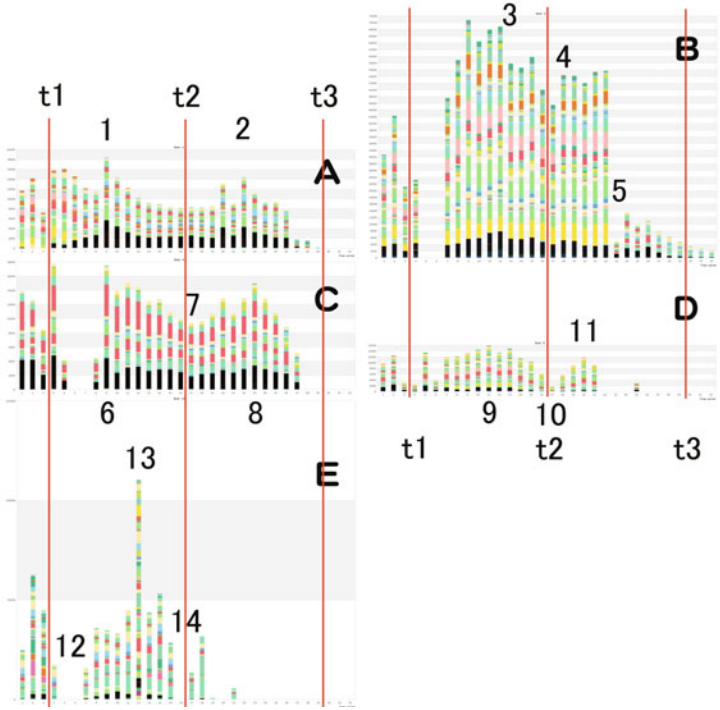

Fig. 2. Time Trends of Residents' Moves

The data concerning their mobilities indicate their activity levels. Fig. 2 indicates some seasonal effects on their activity levels, i.e., they move less in summer due to the heat. There must be some influence from caregivers as well, but the seasonal effects suppress the influence from caregivers.

The knowledge of adherence and mobility for each resident helps caregivers to take care of residents properly. Guradual declines of health are often hard to perceive without data. The analysis enables them to take a proper action by notifying them of anomalies. If everything goes well, the trends must be stable, which may be shown to the family members of residents as a evidence of proper caregivings.

We have shown that we can extract valuable information of the location data. We believe that the result encourages people invovlved in dementia care to collect data and improve their caregivings based on evidences. Future research includes to investigate caregivers' influeces on residents' activities and to apply a probabilistic approach to analyzing the paths.

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Qualitative Spatial Activity Recognition Using a Complete Platform Based on Passive RFID Tags: Experimentations and Results

Kevin Bouchard, Bruno Bouchard, and Abdenour Bouzouane

LIARA Laboratory, Universite du Quebec a Chicoutimi (UQAC)
555 boul. Universite, Saguenay (QC), Canada, G7H 2B1
{Kevin.Bouchard,Bruno.Bouchard,Abdenour.Bouzouane}@uqac.ca

Abstract. Smart home has become a very active topic of research in the past few years. The problem of recognizing activity inside a smart home is one of the biggest challenge researchers have to face in this discipline. Many of them have presented approaches exploiting temporal constraints in order to maximize the efficiency and the precision of their recognition model. However, only few works investigate the spatial aspects characterizing the habitat context. In this paper, we present a new algorithm and a complete experiment showing the importance of taking into account spatial constraints in the recognition process. The goal of this paper is to demonstrate that recognition algorithms will benefit from exploiting spatial constraints.

Keywords: Smart Homes, RFID, Activity Recognition, Spatial Constraints.

1 Introduction

Smart home technologies have become an interesting and very active research trend [1], bringing hope in the effort to postpone the institutionalization of the elders. A smart home can be seen as an augmented environment with miniaturized processors, multi-modal sensors that are embedded in common objects, and software agents communicating between each other [2]. Those environments must take decisions, while remaining non-intrusive, in order to help the resident completing his tasks. The first fundamental step in smart home assistance is to be able to identify the ongoing inhabitant activity of daily living (ADL) [3]. It is exactly why a growing community of scientists [2,4,5,6] is investigating this specific problem. The issue of recognizing ADL consists in interpreting output signals from distributed sensors and to match them, using a knowledge base, with actions and plans corresponding to the possible ongoing activity. The goal is to circumscribe a minimal set of plausible plans (hypothesis) from the knowledge base by using constraints to eliminate the incoherent hypotheses. Most recognition approaches focus on exploiting only logical [2] or temporal constraints [4] while ignoring the fundamental spatial aspects related to objects in a smart home. Nevertheless, these aspects can play a significant role in the recognition process [7]. In this paper, we propose the integration of topological qualitative spatial relations [8] in an activity recognition algorithm to help reducing the number

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of possible hypotheses resulting from the recognition process. We present an implementation of this new algorithm and describe a first experiment conducted on it using a recognition platform based on passive RFID tags [9]. The goal of this paper is to demonstrate how to improve the efficiency of recognition algorithms by introducing spatial reasoning.

The paper is organized as follows. Section 2 presents point set topology basis and the relations we decided to use as a validation case to show the importance of spatial constraints. Section 3 presents implementation of the algorithm and an overview of the platform used for the experimentations. Section 4 details the experimental methodology and presents the results we obtained. Finally, section 5 concludes the paper by outlining future developments of this work.

2 Activity Recognition Based on Qualitative Spatial Reasoning

From researches in the field of activity recognition [2, 3], we can find many examples of situations where exploiting spatial relationships between objects is necessary to obtain efficient recognition results. For instance, imagine that a resident has just executed a certain action named *Boil water*. Let's say that this observation can lead us to two plausible activities, which are *Making a cup of coffee* and *Cooking pasta*. Considering the topological relations between objects, we can detect that a cup is present in (intersecting) the activity zone, while there is no box of pasta nearby. Therefore, the *Cooking pasta* hypothesis could be eliminated.

We propose a new qualitative spatial reasoning (QSR) recognition model able to take into account such situations. We also propose to compare the performance of this same model with and without the use of spatial constraints. A QSR model should abstract the quantitative description of objects and their relations in space in a discrete and simple form. In the context of activity recognition, it seems intuitively appropriate to use purely QSR because of its reduced calculation complexity, and because it better describes the relations between objects.

2.1 The Proposed Spatial Recognition Framework

The spatial model that we exploit can be seen as a specialization of the work of Egenhofer [8], which is primarily based on general topology. We chose this model because the description of spatial relations in terms of general topology is simple and also because it was demonstrated that any topological spatial relations fall within that framework. Imagine each object with a projected sphere around them defining the primitive *region* for the establishment of our relations. If the boundary of the spoon touches the boundary of the cup, it might imply the two objects are in relation for the execution of the activity. If the *interior* and the *boundary* of the spoon are inside the interior of the cup region then it is probably because the spoon is used to stir something inside the cup. As shown on Figure 1, our framework exploits the topological relations between two regions/subsets (A and B). It takes into account eight relations representing all the different ways an object A can intersect an object B in a two dimensional plan according to their interiors and boundaries [8].

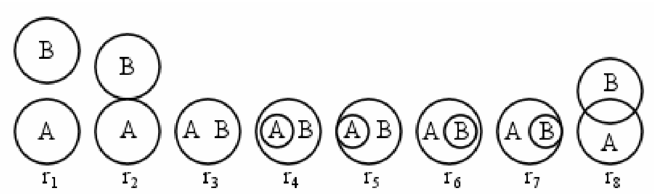

Fig. 1. The eight exploited topological spatial relations

To apply the spatial relationships defined by Egenhofer to activity recognition, we chose to adapt the C4.5 algorithm [10] that uses data drawn from data mining to generate a decision tree for classification (training) and then to predict missing class attribute in a dataset. But, before inferring the activity, we first proceed in a spatial analysis that will circumscribe all possible plans to eliminate those that are absolutely impossible and make a simple sorting of the most plausible. In other words, these relations work like a filter on the knowledge base before the recognition process. A simplified version of the algorithm for spatial assessment is illustrated in Figure 2.

```
For each object a detected by antennas
      Analyze the topological relations of a with other object detected
 For each plan p
      For each topological relation r
          If r respect p =>Augment plausibility of p
          Else If r counter p=>Dismiss plausibility of p
```

Fig. 2. Shorter pseudo code version of spatial analysis algorithm

To reduce operational complexity, we limit the number of objects to be analyzed. To do so, we browse only the objects that could be possibly part of the activity. This includes objects near the subject (in his region), the objects related to them and the objects that have been recently active (movement detection). It is obvious in a real size smart home that the number of objects is large, and that we do not need to analyze all spatial relations, for instance, the relations between inactive objects in the bathroom while the subject is watching TV.

3 Validation

To experiment on this new approach, we chose to use a recognition test platform recently proposed in [9]. The hardware is set up on a table with two antennas in the upper corner and RFID tags on each object. We define a two dimensional Cartesian coordinate to express the position of objects on the table. To do so, we create two virtual circles around the antennas using the object distance as a radius, and we find the coordinate (x, y) where the circles intersect. The basic algorithm worked by using data mining and a decision tree (C4.5) to identify the possible ongoing ADL. A certain amount of training has been done on each possible activity in our library.

To understand the efficiency of the spatial constraints, we added the spatial analysis algorithm like a filter before using the C4.5 to decide. Then we associated a logical region to every physical object (including the antennas) and saved it in the database. We tested different shapes of regions (convex hull, disc, elliptic) and we rapidly concluded that convex hull would be far too complicated, and that elliptic shape would not be possible because we cannot know the orientation of the objects. Consequently, we created the regions in the shape of a projected disc under the objects. The radius of a region is the size of the longest diameter of the corresponding object. The elongated objects (spoons, forks, etc.) are no exception to this condition.

4 Experimentation and Results

For our experimentations, we signed a formal collaboration agreement with our regional rehabilitation center, which provided us with an adequate group of Alzheimer's patients. The experimental protocol is based on a well-known cognitive test named the "Naturalistic Action Test" [11]. We had filmed 25 patients doing the activity *Preparing a coffee* and deducted from there a set of spatial problems encountered frequently. The first identified is the distance issue between objects: *The subject is correctly executing the step to prepare his coffee. Then, he correctly takes the water jar, but he placed it farther on the table instead of nearer.* We can clearly see that the problem will not be detected without considering that the distance between the cup and the jar is increasing. The second kind identified is one of position and it occurs when the system does not considerate that some type of object should never be in regions (shampoo should not be involved in cooking activities).

We have defined three scenarios that both versions of our algorithm tried to recognize five times. The first one was the normal execution of *Preparing a coffee*, the second one was incorporating distance problem and the last one have included a position problem in the sequence. The recognition success rate for the normal execution sequence is almost the same for the two algorithms. However, it took more steps to conclude at the correct plan while not using spatial constraints. For the distance criterion, 4/5 activities were identified accurately and the earlier observations made on normal tests were similar here. However, in the spatial case, we could see that because of a distance anomaly the plan was not taking place correctly. In the last scenario, the anomaly was to produce noise by introducing an interfering object that could never be implied in the kitchen activity. By introducing shampoo, our first algorithm was deceived and never recognizes the activity. To conclude, the results

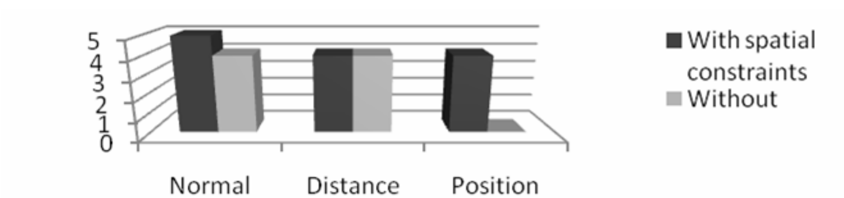

Fig. 3. Number of success in recognition

obtained are very promising and tend to confirm our hypothesis. A summary of the result can be seen on figure 3.

5 Conclusion

Through this paper, we have demonstrated how important the spatial constraints to the recognition process are. For this sake, we proposed a filter built with qualitative spatial relations before the recognition with the decision tree (C4.5). We also presented the implementation of the new algorithm and the first experimentation results that we conducted based on real data gathered in a former experiment with cognitively-impaired subjects. In the future, we intend to improve the coverage of our spatial recognition algorithm and to address the issue of disorientation of objects. Then we will proceed to a larger experimentation with new scenarios of new activities covering each type of spatial attributes (including the one of disorientation). We also plan to introduce new fuzzy spatial constraints that will help dealing with the imprecision of sensors and will enhance the decision process in our algorithm.

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Multiple People Activity Recognition Using MHT over DBN

Andrei Tolstikov, Clifton Phua, Jit Biswas, and Weimin Huang

Institute for Infocomm Research, Singapore
{atolstikov,cwcphua,biswas,wmhuang}@i2r.a-star.edu.sg

Abstract. Multiple people activity recognition system is an essential step in Ambient Assisted Living system development. A possible approach for multiple people is to take an existing system for single person activity recognition and extend it to the case of multiple people. One approach is Multiple Hypothesis Tracking (MHT) which provides capabilities of multiple people tracking and activity recognition based on the Dynamic Bayesian Network Model. The advantage of such systems is that the number of people can vary, while the disadvantage is that the activity recognition configuration cannot be done if only multiple people data is available for training.

Keywords: Multiple Hypothesis Tracking, Dynamic Bayesian Network, Activity Recognition.

1 Introduction

To become practical, Ambient Assisted Living systems have to be able to handle presence of multiple people in the environment. However, so far most research on activity recognition in smart environments is focused on recognition of actions of a single person. In most cases, such systems, being configured for single person, are simply not able to work correctly in the presence on more people. One example of such activity recognition systems are systems based on Dynamic Bayesian Network (DBN) [5], [3], [7].

A possible approach is to take a well-developed method of activity recognition for a single person and try to extend or accommodate it for the case of multiple people. In fact, this was the approach taken by the target tracking community where single object tracking was extended to multiple targets by using *data association* methods, which assigns only a part of sensor data to a particular target. One of the most powerful data association methods is Multiple Hypothesis Tracking (MHT) [1].

This paper describes our early attempt to use a combination of DBN and MHT for multiple-people activity recognition. The contribution of the paper is a track generation method which uses only few sensors in deciding whether a new track must be generated and addresses the problem of sensor readings being shared between different people, which may be a common problem in home environment.

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2 Related Work

Dynamic Bayesian Networks and its special cases such as Hidden Markov Model (HMM) models are popular in computer vision, mostly to exploit temporal information. For learning figure dynamics, Pavlovic et al [5] proposes DBN-based switching linear dynamic system (SLDS) model with an approximate Viterbi inference technique. To interpret group activities, Gong et al [2] uses Dynamically Multi-Linked Hidden Markov Model (DML-HMM) which is built using Schwarz's Bayesian Information Criterion based factorization. Human activity recognition is done using DBN for long-duration activities [3] with the time frame of hours or short-duration activities [7] with the time frame of seconds.

Multiple Hypothesis Tracking was originally developed for radar target tracking [1], however, it was recently used for people tracking as well mainly using analog sensors such as laser range finders or video cameras. A spatial affordance map is a non-homogeneous spatial Poisson process, in order to derive expressions for life-long Bayesian learning. This map computes refined probability distributions over hypotheses in a multi-hypothesis tracker for motion prediction (Luber et al, [4]). Observe-and-explain is able to compute multiple possibilities of tracking with a sufficient amount of observations, even with severe occlusions (Ryoo and Aggarwal, [6]).

Combination of DBN as a low-level filter with MHT for deciding on data association is used by Zaidel and Kröse in [9] for video-based object identity tracking. However, unlike human activity, the actual state of the object identity does not change, therefore building a track of changes in the state is not required. The closest method to ours is proposed by Wilson and Atkeson [8]. The authors described a method of multiple person location and activity tracking which used *Discrete Bayes Filter*, which again is a simple case of DBN, for single person tracking, and solved data association problem by Rao-Blackwellised particle filter. They used simple binary sensors and achieved activity recognition accuracy is about 98% for 2-people and 85% for 3-people.

3 Method Description

MHT creates parallel instances of possible variation of events and allows postponing the decision on how system state changes and which sensor readings should be used for which target until sufficient evidence is accumulated. Hypothesis is a collection of objects being tracked $\mathbf{O}$, each O_i having a track - a sequence of states $(X_i^t, X_i^{t-1}, X_i^{t-2}, ...)$. In the case of target tracking [1], each track may be updated when a radar has an observation, which is a point in space where possible target is detected. New hypothesis is generated whenever there is ambiguity on how track should be updated. An observation may only be used for a target state update if it lies within a *gate*, an error tolerance area around estimated target location. Implicitly, the gate assumes certain probability for these error bounds. In MHT, each observation is assigned only to one target, existing or new. The main steps for tracking with MHT are:

- Acquire sensor data, form observations
- Generate hypotheses, if necessary
- For each hypothesis, assign observations to targets
- For each target of each hypothesis, update target state using assigned observations
- Evaluate and prune hypotheses

For multiple target tracking in airspace, the Kalman Filter is used for changing the state of a single object and MHT decides which sensor data should be used. For multiple people tracking at home, DBN is a filter for updating single person state and MHT provides a set of sensor used by each DBN. However, there are three important differences. First, the state of the activity is an abstract discrete state and the gate in this space is different from continuous space. Second, the sensor data is collected from many discrete sensors and it is not obvious how observations should be formed. And third, in home environment, many sensors may provide shared readings - single sensor readings may be generated and assigned to more than one person.

3.1 Model

Human activity can be presented by a discrete variable with states of this variable describing mutually disjoint combination of actions. Sensing information in home environment is often pre-processed and presented by discrete sensor feature values. The Dynamic Bayesian Network model for recognition of activity is therefore a discrete state model and is essentially a Joint Probability Distribution (JPD) of two time steps of variables $Pr(X^{t-1}, \mathbf{V}^{t-1}, \mathbf{S}^{t-1}, X^t, \mathbf{V}^t, \mathbf{S}^t)$, where X is the state or activity we are trying to estimate, set $\mathbf{S}$ are sensors and set $\mathbf{V}$ are intermediate variables. Dependencies between time slices for X and $\mathbf{V}$ change the JPD $Pr(X^t, \mathbf{S}^t)$ at the previous time step. JPD is used to estimate current state of X using measurements $\mathbf{Z}$, that is $Pr(X|\mathbf{S}^t = \mathbf{Z}^t)$. Part of the DBN are the state prediction model

$$Pr(X^{t+1}|X^t, \mathbf{S}^t = \mathbf{Z}^t) \tag{1}$$

and the sensor gating model

$$Pr(\mathbf{S}^t = \mathbf{Z}^t|X^{t-1}, \mathbf{S}^{t-1} = \mathbf{Z}^{t-1}) \tag{2}$$

The DBN model allows any subset of set $\mathbf{S}$ to be used as evidence for any time step. And since some of the sensor data in environment with multiple people is due to actions of other people, we have to use only partial sensor set provided by a data association solution. However, since the model is only for one person, the dataset used for DBN configuration must contain sensor readings only from single person.

3.2 Data Association Method

In general, for human activity recognition, many sensors readings are important to reach confident estimation. Therefore many sensors need to be assigned to each target at each time step. However, each sensor combination, may potentially give different distribution of $Pr(X^t)$ and, therefore, strictly speaking, different states and gates of the target at the next time moment. However, since there may be exponential number of sensor combinations it is not practical to test all of them. Instead, since we have a discrete state space of the target space given by set of possible values $\mathbf{X}$, and we focus on the most likely state according to current estimation. As an observation, we select only one sensor combination for each possible neighboring state of the current most likely state.

In our approach we define three classes of sensor values:

1. Sensors values which do not need data association, since they provide person ID or bound to specific person. Examples of such sensors are RFID readers or wearable sensors such as wearable accelerometers. The presence of this kind of sensors is required since we want to keep tracking ID of the person doing activities. Information from these kind of sensors is also useful for hypothesis pruning.
2. Sensor values which can provide information related to only one person. Examples are chair occupancy sensor or small door switch. Note, that in many cases the assumption of a single-person may be valid only for certain values and certain features of a sensor. For example, "person sitting" state for a chair is valid only to one person but "person not sitting" is valid for everyone. Similar, the state "door open" can be related to many people, but "door was just opened" only to one.
3. Sensor values which often shared, for example passive infrared sensors; or shared values mentioned above.

We only need to solve data association problem for classes 2 and 3. In our method we focus on the tracks, that is sequence of states from each person, rather than hypotheses as collection of tracks. We define track as a sequence of states $(X_i^t, X_i^{t-1}, X_i^{t-2}, ...)$ produced by a given DBN model and sensor input $(\mathbf{S}^t, \mathbf{S}^{t-1}, \mathbf{S}^{t-2}, ...)$ by any valid sensor assignment $(\mathbf{S}_i^t, \mathbf{S}_i^{t-1}, \mathbf{S}_i^{t-2}, ...)$. The assignment is valid if for a given hypothesis the sensor assignment to targets of the hypothesis all values of the class 1 above are always assigned, values of the class 2 are assigned to at most one target and sensor combination for each target is feasible, i.e. the probability in the Equation 2 $Pr(\mathbf{S}_i^t = \mathbf{Z}_i^t | X_i^{t-1}, \mathbf{S}_i^{t-1} = \mathbf{Z}_i^{t-1}) > 0$

For each time step of the DBN tracking a single person, we do the following actions:

1. For each track i
2. Using prediction from time moment $t-1$ (Eq.1) find the most likely current state X_{max}^t
3. Assign all sensors of class 1
4. If assignment is not feasible, terminate track
5. Assign all the sensors of class 3 and valid sensors of class 2 for which probabilities $Pr(S_j^t | X_{max}^t,)$ are above some small (i.e. 0.05) gating threshold α (for both classes). Total sensor set for steps 3 and 5 is now $\mathbf{S}_{max}$
6. Find neighbor states of X_{max}^t, $Pr(X_k^{t+1}) > \beta$ for $X_k^{t+1} \in \mathbf{X}_\beta^{t+1}$

7. For each $X_k^{t+1} \in \mathbf{X}_\beta^{t+1}$
8. Assign sensors as in step 3 and 5
9. If for X_k $\mathbf{S}_k \neq \mathbf{S}_{max}$, generate new track
10. If there are other tracks for the same target having the same X_{max}^t, merge tracks by leaving the most probable

3.3 Evaluation

We evaluated the proposed method using simple scenario of two people using shared space and doing some basic activities such as answering phone, using cupboard, sitting on the chair and eating. The ID of the person was established by a wearable accelerometer to evaluate the tracks and by the RFID at the entrance to detect the presence. The DBN shown in the figure was obtained using collected data from a single person present in the environment. Although the scenario is simple and therefore DBN model has a good recognition performance, the addition of MHT allows resolution of sensor conflicts.

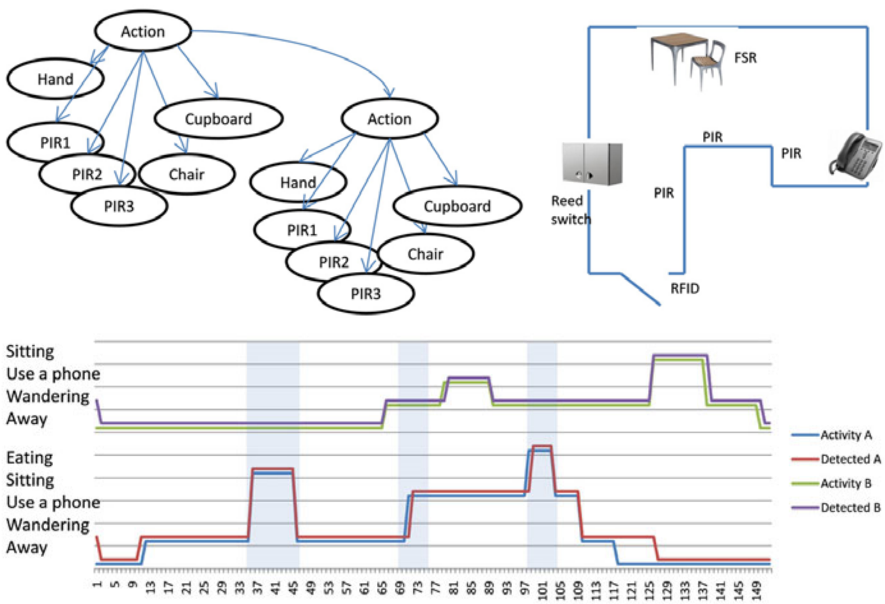

Fig. 1. Structure of the DBN used for both subjects and a simple map of the installed system (top). Results for simple two-person scenario - shaded areas mark the moments when additional hypotheses have to be generated (bottom)

4 Conclusion

We provided an outline of multiple people activity recognition in home environment. The method uses Dynamic Bayesian Network model of a single person's activities which is extended to multiple people case by using Multiple Hypothesis Tracking for data association. The early experimental results show that this method may be successful in tracking activities of multiple people in the system with sensors that provides shared readings.

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Approaches to Smart Home with a Focus on Workspace in Single Household

Hee Hwa Chae and Mi Jeong Kim

Department of Housing and Interior Design, Kyung Hee University, Seoul, Republic of Korea
hee0462@gmail.com, mijeongkim@khu.ac.kr

Abstract. Single-person households have appeared recently as one of new distinct family types in Korea and lived mainly small scales of studio apartments and flats. However, we expect that normal large scale of houses or apartments will be inhibited by the residents of them in Korea. Accordingly the demands for their home would become dynamic like those of the other family types because their housings will not be temporary choices. The research proposes a direction for the development of smart homes in Korea, especially, for single households with a focus on their home workspace. Based on the results of a case study, a home workspace was identified as the highest need of the single households. Thus, this research emphasizes the effective functioning of home workspace and suggests intelligent components for it by introducing enabling technologies and notions to the development of the smart homes.

Keywords: Smart Home, Single Household, Workspace, Ubiquity, Mobility.

1 Introduction

With the transition from the machine age to that of information technology, our society has been restructured, which influence family life styles and organizations, leading to various types of families. One of new distinct types emerged in Korea is single household composed of one resident as a family [1]. The house types for single households have centered on small scales of units such as studio apartments and flats [2]. However, we expect that the increasing number of single households would affect the Korean housing market, thus new forms of houses that reflect their dynamic demands will be produced for single households shortly. In the near future, single household will be a common family type and their housing will not be stayed in the form of temporary small sizes of places in Korea. The advancements in digital technologies have transformed the forms and spaces in which we live. The demand for single households is recently increasing in the development of smart homes in Korea. This paper provides an overview of enabling technologies for smart homes in abroad and domestic markets. In addition, the result of a case study will be provided to identify resident experiences and demands in single households. Based on the background knowledge, we will propose a direction of smart homes for single households with a focus on home workspaces.

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2 Technological Advancements in Smart Home

'House_n' in MIT and 'Aware home' in Georgia institute of technology have focused technical solutions for health care of the elderly and explored future housing designs based on user behaviors in their experimental spaces, where residents' living patterns are being real-time monitored through a variety of sensors [3,4]. 'Home project' by Microsoft has offered new visions of user interfaces in smart homes and provided a systematic scenario of smart structures embedded in architectural components and artifacts invisibly for future digital housing [5]. Most of the smart home projects have focused on the support of special groups such as the elderly and disabled, furthermore, developed home network systems and products depending on the physical features of their existing houses where they have lived for a long time. Developments of smart homes in Korea are fundamentally similar with those of other countries. However high-technologies have been adopted for a large apartment complex rapidly with a focus on commercialization as a marketing strategy, without considering much resident's home life styles. Samsung developed 'U plan' as a combination model of ubiquitous technology with housing technology and propose 'U city' as the ultimate service level for smart homes [6]. Hyundai developed a portal service of home networking that supports services such as multimedia, infotainment, education, communication, health care via a set-top box, where residents can get useful information of life through TV [7]. Many construction companies in Korea have realized a ubiquitous computing environment in their exhibition halls as a prototype of the smart homes with the aim to put an advertisement of their companies.

3 Case Study: Needs and Features of Single Household

Survey was conducted by 200 men and women of 20s and 30s single households. The small sizes of temporary housings do not include specific residential facilities because they usually consist of one main living area with a separated bathroom. Thus the one area is supposed to be used for all functions, which has caused no consideration for detailed components in support of the single households' life qualities [8]. We expect that the housing types of single households will be almost the same as those of current common family housing in the near future. In our case study, single households were asked to answer to our customized questionnaire regarding their perception and needs of smart technologies. Over 40% of them have professional occupations and almost 30% of them are students. The types of their housings are divided into 3 types; one room sharing in detached houses (27.5%), small apartments (26%) and studios (11%). They considered bedroom function as the most important one to be designed (49.5%) in their housing. In the survey of their needs on support facilities, they mainly wanted an effective functioning area where they can use computers and supporting technologies (89.5%) for their professional works. In conclusion, the demand of workspaces equipped with smart technologies and telecommunication is distinctively high, however, the previous studies of smart homes have not considered the need of workspaces in smart homes sufficiently.

4 Potential of Workspace in Smart Home

The rapid development of mobile and ubiquitous technologies has provided people with the ability to work away from the office [9]. Our research is intended to suggest the future direction for smart home workspaces especially targeted for single household. For the development of the effective functioning workspaces in smart homes, it is necessary to review leading technologies that can support residents' connection to their partners and information. Through the reflection on these technologies, we aim to better understand the potential of workspace in smart homes.

4.1 Enabling Technologies and Interfaces

Tele-presence technologies combined with high bandwidth networks have allowed people to contact with their colleagues at home. In this research, we consider the extended version of the tele-works for individual works in smart home workspaces. There are various technologies that can connect residents in single households to their professional domains, not limit them at home. The most distinct concept for recent workspaces is a ubiquitous office where user can utilize computing technologies intuitively without recognizing the computers [10]. Activating as pervasive computing, mobile platforms such as smart phones enable the workers to be connected to other devices and colleagues at any time [11]. Mixed Reality (MR) technologies overlap computer-generated information onto the physical environment, thus enabling augmented interactions in real context. Tangible User Interfaces (TUIs) become one of critical issues to user experience and perception. By encouraging tangible and full-body interaction, TUIs enables embedding computing in the physical environment and supporting intuitive uses beyond the traditional desktop and graphical user interfaces (GUIs) [12]. This research adopts the notion of context immersion [13] as a novel approach to the embodiment in ubiquitous, mobile and tangible computing in smart home workspace. The concept of immersion is described as a psychological state of being enveloped by an environment that allows users a continuous stream of experiences [14]. The immersion can be generated by the visual, acoustic, haptics, and motion characteristics as well [15]. Rather than adopting confined displays isolating residents completely from the real context, context immersion enables seamless interaction between the real and virtual domains utilizing the strength of mobile, ubiquitous and ambient media, thus activating a new working environment.

4.2 A Unified Approach to Tangible and Pervasive Home Workspace

A tangible and pervasive home workspace is an active information-oriented office, beyond the desktop works, supporting the residents' mobility and working experiences. This approach emphasizes the embodiment of physical spaces and tangible interaction in a computer mediated environment. The tangible and pervasive workspaces can be a hybrid environment by combining MR and TUIs for interaction and communication with the smart devices and other members. The horizontal and vertical surfaces of the workspaces or all artefacts can be augmented for the visualization. Many people usually work as a member in a team or an employee in a company although they often work individually. That is, many of people in principle do not work alone, but collaborate with other people in reality. This is why they need to be connected to the members and work contexts through the intelligent network systems. The home workspace can be divided into two features. One is the tangible attribute that lowers the threshold for activity and produces embodied interaction in spaces. The other is the mobile attribute that enables people to work on the move and to access to information and people anytime, anywhere. This mobile attribute is associated with ubiquitous computing, which has territorial characteristics, thus provides appropriate services by identifying the context of the works. Furthermore, it can be also regarded as a non-territorial technology because it produces mobile settings where works can be performed beyond the limitation of time and space. In order to develop smart home workspaces, we developed a unified approach to tangible and pervasive home workspace as illustrated in Fig. 1. Accordingly, in order to realize smart homes with a focus on the intelligent workspaces, the above approach to technologies should be adopted. This approach would be a theoretical basis for embodying the intelligent home workspace which supports residents' professional works in single household efficiently and effectively.

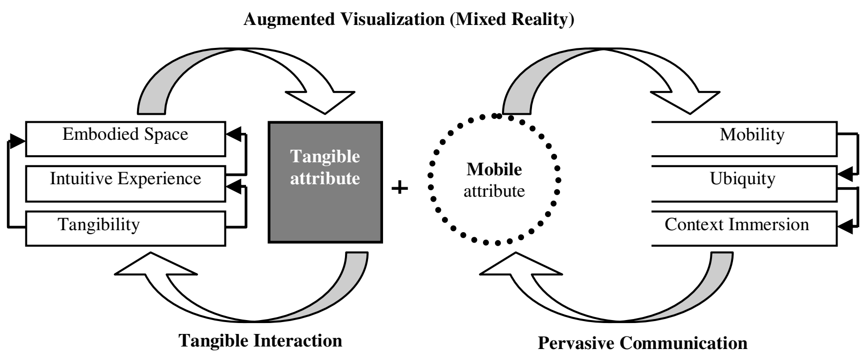

Fig. 1. A Unified Approach to Tangible and Pervasive Home Workspace

5 Discussion and Future Direction

This paper deals with the potential of intelligent workspaces for single household as one of significant issues by presenting a novel approach to the development of smart homes. The related research and technologies to support residents' works and communication were reviewed. Furthermore, this paper provides a united approach to tangible and pervasive office with a focus on human interaction and experience. The primary notion for our research is enabling communication. People in single households are not secluded, rather could be connected to their work context through the smart technologies. Thus, their working time and space can be expanded and flexible in ubiquity and mobility. The elderly and disabled might need home workspaces because they have much difficulty in accessing their workspaces outside with the limitation of physical capabilities. Thus, a computer mediated workspace is one of important research issues for the development of smart homes. A growing number of researches and technologies in mobile, ubiquitous computing, MR and TUIs would be adopted in support of residents' experiences and interaction in smart home workspaces. The most crucial to the development of smart homes should be started from the understanding of residents' demands in their life styles, thus leading to supporting systems and services for them. This research can be a basis for the future direction of the development of smart homes and extended by further studies including more case studies for the evaluation of our arguments.

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