An Ambient Assisted Living Monitoring System for Activity Recognition – Results from the First Evaluation Stages

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Abstract. In a study 100 households will be equipped with a low-cost ambient monitoring system for activity recognition. These monitoring systems should identify emergency situations and evaluate the health state of a person. Complemented by the support of service providers from the area of nursing, additional reference information through interviews and self-documentation is collected. Through a central web platform all data is bundled and linked together. We will present initial results from the evaluation in the form of a preliminary study with 14 subjects. They form the basis for the rollout in 100 households.

Keywords: AAL, ambient assisted living, monitoring system, activity recognition, smart meter.

1 Introduction

The median age in more developed countries will rise till 2050 from 39.4 to 46.1 years [1]. Hence, in the following decades we are confronted with an increasing elderly population. The amount of people in need of care will grow. Additionally, costs for health treatment are rising already to the extent that the financial power of health care systems will be exceeded soon. On the other side a limited number of care givers and facilities for ambulant or inpatient treatment will be available. New care concepts and services like ubiquitous nursing [2] are needed to cut costs in healthcare and still providing a secure life and adequate treatment for elderly people.

Part of the research in the Ambient Assisted Living (AAL) environment is currently driven by developments in the home automation sector. These technologies are put into new concepts around the topic of behavior analysis in the home environment. These monitoring systems have to identify short-term emergencies and long term variations of the health status. For analysis and interpretation of sensor data generally the machine learning or rule-based methods (Markov chains, neuro-fuzzy approaches, etc.) are used.

For financial reasons, so far, only a small number of households with real users were put into practice (e.g. in the EMERGE project [3] 2 flats over 3 months, in the

eHome project [4] 11 apartments over a total of 553 days). The development of algorithms with machine learning methods need a solid database with a substantially greater number of cases in order to achieve reasonable results. In current research projects, such as SAMDY [5] and eHome [4], the system costs are estimated between 3,500 € and 5,000 €.

Therefore, the installations of such technologies in a larger number of households, that allow a monitoring of daily activities, are very important. They form the basis for future research on emergency detection and health assessment.

2 Study Concept

As part of the project optimAAL, a study was planned, to capture activities of daily living in a home environment by using a low-cost AAL system. In this study the evaluation of 100 households should be enabled through the integration of external service providers and by using the existing hard-/software infrastructure.

2.1 Objectives

In this work, we set the following goals to achieve the best outcome for our project:

- Develop a low-cost ambient unobtrusive monitoring system (<1000 €)
- Evaluate the monitoring system in 100 households of the target audience for a duration of 18 months
- Collect reference data from assessments and self-documentation
- Establish a central platform to gather monitoring and assessment data
- Give access to other researchers to offer them datasets for testing their algorithms.

For the first time we can capture real data in a larger scale and provide a basis for the development of future assistive systems. Researchers will get access to an anonymous database for activity recognition, as in other areas, such as the signal analysis of the ECG or voice recognition.

The study will provide the possibility to gain experience in the roll-out of new services beyond laboratory conditions. This is considerably important in the preparation of potential commercial implementations of assistive services.

2.2 Study Design

For the realization of the study an ambient monitoring system is installed in 100 households. The care of the volunteers and the collection of reference information (personal interviews, telephone interviews) are supported by external service providers (care providers / daily carers / emergency services). The measured sensor values and the collected survey data is transmitted to a central web platform and linked to each other. (Fig. 1)

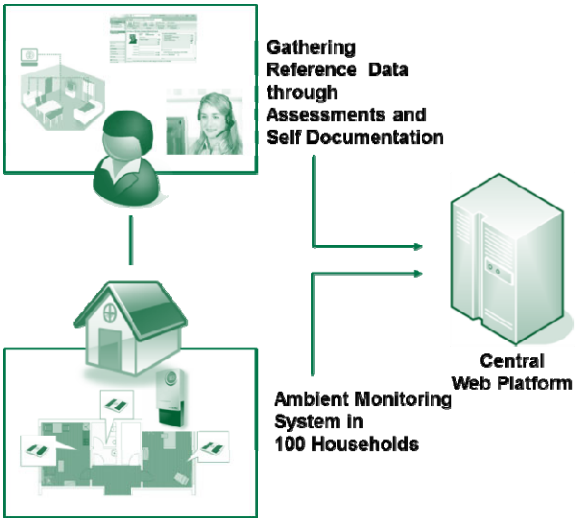

Fig. 1. Study Concept

3 Implementation of the Study Concept

For the implementation of a socio-technical study both the technical part, such as the ambient monitoring system (smart meters and home automation) as well as the social part (carers and volunteers) have to be considered. The central web platform bundles all the information.

3.1 Ambient Monitoring System

In the development of the monitoring system (Fig. 2) we will use existing technologies and services from the area of home automation, smart metering and wireless communication.

Smart Meter

The topic of smart metering has become increasingly important in recent years. By opening up the market for metering operations [6], new companies ventured into this area. These companies get the attention because they develop new business models based on energy saving and tariff advice.

The data of the smart meter cannot only be used for billing, but also for behavioral analysis and activity recognition. Any variation in power consumption is recorded. This means that all household appliances, e.g. stove or television can be derived from energy consumption. By abstracting the recognized appliance, we can detect certain activities.

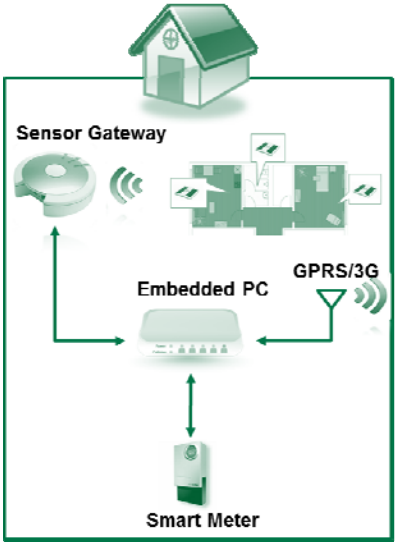

Fig. 2. Technical Concept of the Monitoring System

As of January 2010 newly built homes and renovated buildings in Germany have to be equipped with Smart Meters. Because of this legislation more and more homes will have a smart meter already installed [6].

A meter operator was contracted as a service provider for the study to conduct the installation and operation of the smart meters. They already provide a service that analyzes the power consumption of its customers and demonstrates ways to reduce the consumption with minimal effort. Through a web interface energy data with a sample rate of 0.5 Hz and abstract appliance information is transmitted.

Home Automation

The ambient monitoring system consists of home automation sensors in addition to the smart meters. Requirements apart from the unobtrusiveness of the sensors are especially the ease of installation and the need for low maintenance. Hence the focus lies on wireless, battery-powered technologies.

We examined several commercially available home automation products, like EnOcean, Moeller xComfort or Z-Wave. EQ3 Homematic turned out to be the only system that matched our budget.

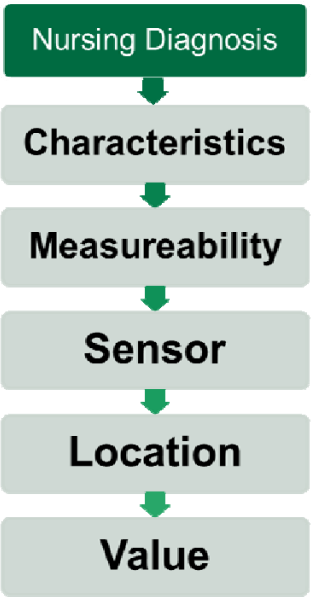

Fig. 3. Sensors derived from Nursing Diagnoses

Before you equip households with sensors, it is important to identify what features and activities you would like to detect. For this reason, we developed a list where nursing diagnoses were connected through their characteristics with a specific sensor and his location (Fig. 3). As a next step, we matched the specified sensor with the selected Homematic system. Because not all nursing diagnoses can be presented, the sensor mapping is demonstrated by four activities of daily living (ADLs), which give the most comprehensive insight into the person's health (see Table 1).

For example, "washing and dressing" can be derived from the data of a motion sensor and humidity sensor in the bathroom. Some sensor positions must be described more specifically than others. Above all, contact sensors are attached to specific locations like the refrigerator or toilet flush.

Motion detectors are best placed in a location where the whole room can be monitored for movement. Therefore, furniture is the major obstacle at home.

Data Processing and Communication

A PC in the nettop format is placed in the household of the subject. It collects data from home automation sensors and the smart meter. Via Power Line Communication (PLC) electricity consumption values are read from the smart meter. Sensor messages are routed from the sensor gateway via Ethernet. An UMTS connection is established to submit the data to the central web platform.

Table 1. Selection of ADLs according to [7] matched with sensors

ADL	Sensor	
	Type	*Location*
Washing and Dressing	Humidity	Bathroom
	Motion	
Washing and Dressing	Contact	Closet
	Temperature	Bedroom
	Motion	
Elimination	Motion	Toilet
	Contact	Flush
Mobilization	Motion	All rooms
	Contact	Entrance door
Eating and Drinking	Contact	Cupboard
		Fridge
	Motion	Kitchen

3.2 Stakeholders

Due to the large-scale study, service providers from nursing will be commissioned to take care of the volunteers. They represent the main contact person and conduct the assessments.

As a main target group, households were identified where elderly live on their own and are at least 65 years old. They represent the clients for future products in the field of monitoring systems. People living by themselves are particularly vulnerable in emergency situations due to the fact they possibly cannot react adequately. For the study the test person should be largely independent in their mobility and mostly live on their own. No exclusion criterion is an hourly care by relatives or nursing services. The participants receive a free home emergency service, as a motivation to participate and as a first step towards more safety at home.

3.3 Reference Data

The collection of reference information is essential to evaluate the data of the ambient monitoring system. Thereby two levels of abstraction are important. On a lower level plausibility of sensor data is assessed by matching it with the reference data, e.g. the correct distinction between inactivity and absence.

On a higher level of abstraction the health of the subjects have to be linked with behavioral data. Assessments will determine the health state of a subject. This can be used to determine what information and indicators data is hidden in the abstracted sensor data.

The assessment consists of two parts: interviews and self-documentation. At the beginning and at the end of the study, personal interviews are conducted. In monthly telephone interviews abbreviated questionnaires are performed. Diaries are handed

out to the participants in order to record special events throughout the day and therefore assist the caregivers.

Assessment

In the case of conducting questionnaires, the interrater variability is an important aspect. The variability influences the classification of the health state of subjects. In order to still provide comparability, we analyzed various validated assessment tools and compared them with our requirements.

In the geriatric field and in the nursing environment different assessment tools are available. Among others the following tools are interesting for our application [8]:

- Barthel Index
- Clock Completion Test
- Geriatric Depression Scale
- Geriatric Screening according to Lachs
- Hamilton Depression Scale
- Mobility Test according to Tinetti
- Mini Mental State Examination (MMSE)

Every single tool is giving information about specific fields of a person's state. To cover more fields of health and mental state a combination and modification of these assessment tools is needed.

The differing background of caregivers must be considered. This means that the assessment must be easy to understand and well conveyed. This way you can retain some degree of validity of the responses.

In our questionnaire we included mainly questions from the areas of:

- Cognition
- Mood and Pain
- Social Interaction
- Mobility (Gait, risk of fall)
- Nutrition
- Sleep
- Hygiene
- Dressing
- Sensor Acceptance

We derived an interview guideline with approximately 80 questions. The interview has exactly verbalized questions and thus offers a good guidance for the interviewer.

Self-Documentation

The gathering of information by diaries can be found in many areas, e.g. in market research in order to receive specific feedback on a product. In this study we will collect daily data through multiple-choice questions about the well-being, health and leisure activities. The diary can be used by the carers to follow up with more precise

questions. Moreover, the information can be used to detect erroneous messages from the sensors.

3.4 Central Web Platform

Sensor data from the distributed households must be linked with the survey results. Therefore, a central platform for storing and managing all the data is necessary.

Data from 100 households will be collected over a period of 18 months. This requires a scalable platform. Because of the web framework used, the application can be extended with libraries. Hence, new services can be integrated easily.

For the protection of personal data, a pseudonymization was implemented. User rights are restrictive. Nonetheless, the web platform needs to be accessible to different user groups and provide customized views.

The technician needs only an overview of the functionality of the monitoring system. It has to represent both, the functionality of the individual sensors as well as the reliability of the entire system. The carers conduct the interviews and the responses of their subjects are filled into the web application. Researchers have access only to an anonymized database of behavioral information and reference data.

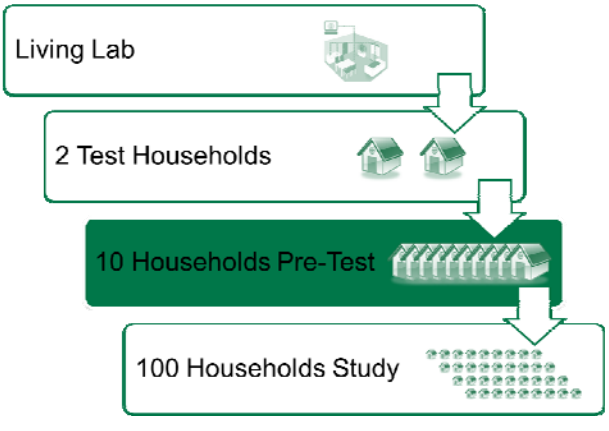

Fig. 4. Evaluation Process

4 Evaluation

To ensure a satisfying process of the study an evaluation-driven development and study process was chosen. Through four evaluation phases (Fig. 4) the AAL system is introduced. We started with testing and evaluation of the prototype by using the AAL Living Lab environment. A long term test in two friendly households made sure that

the sensor technology is reliable enough to be used in a preliminary study with 14 households to verify the study concept.

4.1 Test in the Living Lab

The FZI AAL Living Lab [9] offers the possibility of testing and evaluating prototypes and use cases. For example, the monitoring system can be installed in a real household environment, so that the end user can be involved at an early stage of the project.

In the Living Lab (Fig. 5) the behavior and operation of the sensors was examined. In a workshop, the sensors were presented to nursing providers and potential barriers in the field study were discussed.

Fig. 5. Model of Living Lab at FZI

Sensor Behavior and Operation

Home automation sensors send messages in different intervals depending on the configuration. The function of a sensor can be verified by checking the frequency of messages. For example, if a contact sensor sends not at least one message a day, we can assume that the sensor is not operating well (Table 2).

If the study participant replaces the sensor from its original position, it is indicated by the sabotage protection detection. An internal contact to the housing may recognize the replacement. You can determine if all sensor values were received by the sensor gateway with the help of a counter.

Table 2. Sensor Characteristics

Sensor	*Frequency*	*Durability*
Motion and Brightness	15s (during motion) 2-6 min (without motion)	> 1 year
Temperature and Humidity	2-3 min	< 3 years
Contact	Once every day (Alive-Message)	> 2 years

Tests were carried out with motion sensors. In a 20 square meter area with a distance of at least 2 m to the sensor different activities were performed (Table 3). This will show us the sensitivity of the motion sensor. The sensor detected every 5 s movement in a room. Thus, no accurate statement can be determined to the speed of the person moving between different rooms. However, the resolution is sufficient to estimate the mobility of a person. Slight movements of the arms or legs in the state are not sufficient to trigger a sensor message. Whole body movements are detected reliably.

Table 3. Activity Test – Motion Sensor

Activity	*Detected?*
Entering room	Yes
Opening the door	No
Movement of objects	No
Movement in bed	Yes
Movement of arms	No
Movement of legs	No
Only head movement	No
Lying down	Yes
Moving from sitting to lying	Yes
Moving from sitting to standing	Yes
Moving from standing to sitting	Yes

The opposite of motion, inactivity, such as sitting on a chair, cannot be measured directly. Merely by history and context information, e.g. when changing positions, it is possible to recognize a certain activity.

The humidity sensor is used in the bathroom for detecting the activity "washing". Usually the air humidity ranges between 50% and 60%. By using the shower, the humidity rises above 80%. The higher value remains for the duration of the showering process and falls back to the initial value with delay.

The brightness during the day is usually between values of 30-40. When switching on the lamp the value increases up to 100. The values aren't in accordance to any general scale. They are sensor specific values.

4.2 Non Target Group Test Households

The monitoring system was evaluated in two friendly households. The reliability of the sensor system in the form of a long-term investigation played an important role. Errors and transmission issues on the PC and server side could thus be eliminated.

An installation guide for locating the sensors in the household has been developed to achieve a highly efficient installation process during the field study.

4.3 Preliminary Study - 14 Households from Target Group

The aim of the preliminary study is to identify obstacles and issues that have not occurred under lab conditions. For the first time, work processes for acquiring participants and installation were applied. They have been developed during the evaluation and discussion with service providers in the Living Lab.

Acquisition

The acquisition was done through sub-contracting service providers from nursing and home emergency services. This has been proved to be a very successful approach. The existing contacts and customers of the service providers could be accessed directly. The employees were trained in a workshop and are also supported with flyers and brochures. As a result, it can be stated that almost 25% of all addressed persons have decided to participate in the study. This is an extremely high value in comparison to the approach of only distributing flyers or brochures. However, an increased time of 1.5-3 h was required to inform candidates about the study.

Study

In the preliminary study the planned schedule was tested. Questions especially concerning the feasibility of the study had to be answered.

The planned duration for the first interviews was set between 60 - 70 min. The questionnaires are quite extensive, so that only real interviews can prove if something needed to be reworked.

The first 14 personal interviews lasted an average of 54 min, with values between 30 - 90 min. Hence, the scheduled time was confirmed. Talks with dementia-diseased subjects had to be set longer. Important in the fast completion of the questionnaire was mainly to keep the participants focused. Elderly often tend to tell anecdotes from their life. The interviewer must be polite but determined to pursue the questionnaire.

In the beginning there was the concern to what extend the diary will be filled out by the participants. The return of the first two months, however, was promising: 60% of the diaries were returned completely filled out. With their information about the activity and absence, illness and mood, they form an important part of the reference data. Unfortunately, elderly with dementia can't keep up filling out the dairy.

Technical Experiences

Two things proved problematic during installation of the sensors. On the one hand the correct location of the UMTS sticks is of great importance and on the other hand the surface on which the sensors were glued may be a major issue.

For quality assurance, all sensors and their supplied batteries are tested in advance. It has unfortunately been often shown that batteries were dead or getting very hot after installation.

In rural areas the coverage with GPRS / UMTS is rather low, so that in our case it was essential that the UMTS-Sticks were attached directly to the windows. At home the coverage was very fluctuating.

A major issue proved to be the installation of sensors on tiles in wet environments. The conventional attachment using power strips or double sided moisture resistant adhesive tapes revealed no long-term satisfactory results. With an additional primer for the Power Strips, we found a way to get long-term durability even on slippery surfaces.

During on-site installation the sensitivity of the contact sensors on metallic surfaces was another hurdle. This problem could be solved through the use of spacers. This situation occurs with refrigerators as well as with doors and their frames.

The monitoring systems in the households were 75% of the time online and more than 80% of the requested data transfers were carried out successfully. At this early stage of the study it is a very good value. With the help of the Linux-based PC solution we further optimized the reliability and stability. This is mainly based on the over-the-air update functionality and remote configuration. The software in all households can be kept updated with current releases. As the biggest influence on the pre-study has been the problem with the UMTS network.

Participant Feedback

The focus here is on a qualitative summary of the responses, given the small number of subjects in this preliminary study.

In general, the participants are very interested and understand the purpose of the study for future assistive systems. Elderly with dementia had to be convinced especially by their relatives.

The falling down of the attached sensors felt to be very disturbing, so that there was additional support needed to explain the issues.

The diaries were rather annoying to some participants. However, the cares highlighted the importance of the diary in this study. Subjects with dementia cannot fill out the diaries.

All in all there is great interest in the study among the study participants, but it is necessary to support some participants especially with dementia more closely. For many elderly the study is a welcoming change of their daily life in a rather lonely environment. The social skills of the nursing service are of great value in dealing with the participants.

5 Conclusion and Outlook

First experiences in the evaluation of a monitoring system to collect behavioral data in a study of 100 households were presented. A cost-effective ambient monitoring system based on smart meter technology and home automation sensors has been developed. Service providers from the nursing care support the study participants and collect reference information through questionnaires and diaries. A central web platform bundles all the information and offers these to specific user groups.

The behavioral data provides for the first time the opportunity to use different methods of machine learning with the help of a solid data base and support future developments of AAL systems and algorithms of the ADL detection.

The evaluation-driven monitoring system was developed. After successfully building the first prototype in the FZI AAL Living Lab first behavioral and functional tests were performed. In consequence two friendly test households were used to gain more experience with the sensor system and the central web platform.

The next step was an evaluation of the entire concept in a preliminary study with 14 households with participants of the target group. In general, the feedback from volunteers and carers was very positive and the monitoring system works very reliable. Currently, preparations are made for the rollout of the 100 households.

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