Introducing a low-cost Ambient Monitoring System for Activity Recognition

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***Abstract*—Within an aging society new approaches to support elderly people to live on their own are gaining a lot of attention. In the context of ambient assisted living we developed a low-cost ambient monitoring system for activity recognition. The system is based on smart meter technology and home automation sensors. First test installations in a living lab environment and in non-target group households showed promising results regarding the projected rollout in 100 households. Reference data is collected through assessments and self documentation. We established a central web platform to connect the monitoring data with assessment results. In the future researchers will get access to the database to develop and test new assistive systems.**

Keywords-monitoring system, activity recognition, ambient assissted living, smart meter

I. 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.

In the context of ambient assisted living (AAL) new technologies are driving the development of assistive systems. Especially monitoring systems for activity recognition are gaining more and more attention. Short-term situations and long-term deviations are the focus of systems developed in research projects like EMERGE [3], PAUL [4], eHome [5] and SAMDY [6]. They develop monitoring systems based on home automation sensors.

Costs of ambient sensor installations presented in those projects are relatively high. The SAMDY system is estimated at 3500€, the eHome configuration costs about 5000€. Due to this fact field tests are restricted to a low number of installations (<20). In conclusion results about the benefit of ambient monitoring systems are limited due to the relatively small amount of accumulated data.

Another missing part in the development of assistive systems is a standard dataset or database for testing new algorithms for activities of daily living (ADL) recognition. In other fields, like signal processing of ECG or speech recognition, databases are accessible for every researcher. They test their new approaches using the available data without building the real system for themselves.

II. 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 6 months
- Collect reference data from assessments and self documentation
- Establish a central platform to gather monitoring and assessment data
- Give database access to other researchers to offer them datasets for testing their algorithms and developing new assistive services in the AAL context.

To match our goals first we defined a technical concept of the low-cost monitoring system (Fig. 1). Secondly an assessment concept was developed to deal with the issue of collecting and connecting reference data to the monitoring data. Lastly we performed an evaluation of the monitoring system in a living lab environment and in test households.

The differentiation from other projects lies on reduced system costs, a study setup with a much higher amount of households and in the support of the study persons through interviews. Furthermore we want to investigate the necessity of integrating the monitoring system into a service or care concept. This includes the question of how such a concept can be funded.

III. Technical Concept of a Low-Cost Monitoring System

To develop an ambient monitoring system we need unobtrusive sensors. These sensors should be capable of

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recognizing activities of the monitored subject to later abstract the sensor information for activity recognition. To fulfill the requirement of a low-cost system the focus will be on market available home automation sensors. In addition Smart Meter technology will be used to reduce the amount of installed home sensors.

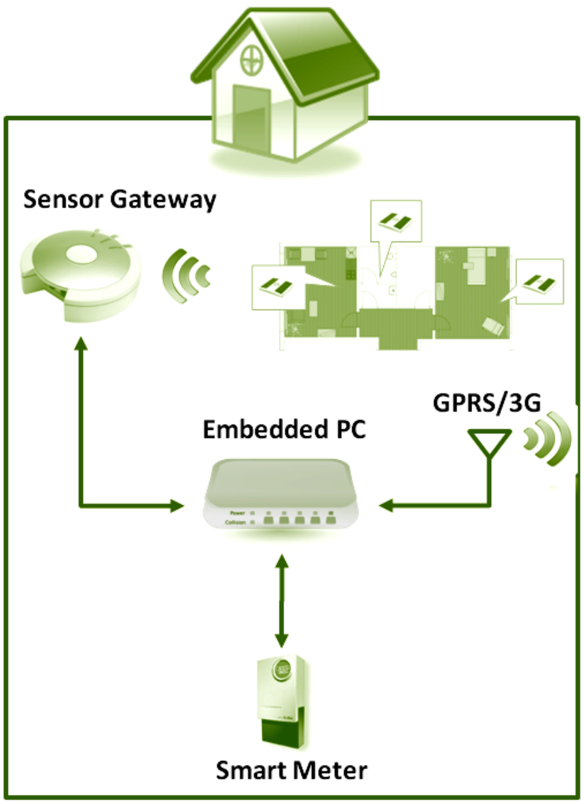

Figure 1. Technical Concept of a low-cost monitoring system

A. *Smart meter*

Smart Meter technology gained a lot of attention in the last few years, because the power supply system has to deal with different kinds of renewable energy suppliers. Smart Meters help the system operator to match supply and demand of electricity, moving towards intelligent supply systems called smart grids.

The data supplied by the smart meter can also be useful in the area of activity recognition. The smart meter detects every change in power consumption. Therefore every appliance, like a stove or TV, will be reflected in the load curve. Hence, the activity level of a person at home can be determined by aggregating smart meter data.

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 [7].

To use smart meters in our project an experienced partner is necessary. This partner will not only supply smart meters but also give access to the power consumption data at a sample rate of one value per second. Values provided by the utilities are usually cumulated 15 minutes power consumption data.

B. *Home automation*

Apart from the smart meter, a set of home automation sensors will be installed in the households. The ambient sensors should be easy to install in existing homes. This leads to a system of wireless battery or battery-less powered (e.g. solar, thermal, kinetic energy) sensors. To choose one home automation technology that fits our requirements a comparison was done.

1) *Technology comparison*

Four different home automation technologies were determined as possible monitoring systems through a first rough selection. In TABLE I the different technologies are compared. The home automation systems sold on the market usually differ in price, available sensor types, power supply and ease of installation. We defined a standard set of sensor types which should be available:

- Motion Detection
- Brightness
- Temperature
- Humidity
- Contact

Moeller XComfort and Z-Wave lack the humidity sensor, which is important for the ADL recognition (TABLE II).

The different sensor types should last at least 6 months without exchanging batteries. Otherwise a technician has to drive to houses to fix sensors. EnOcean uses energy harvesting to power sensors which results in a maintenance free system. The others use batteries, which last depending on the sensor at least one year.

The XComfort system needs wires for their contact and temperature sensor. This makes installation more time consuming than other systems.

Concerning prices a standard home automation package including five motion/brightness, three contact and two temperature/humidity sensors were compared. EnOcean sets the highest price because of their unique energy harvesting solution. Also XComfort is in a price range well above 1000€. ELV Homematic offer the most reasonable price at 500€.

TABLE I. HOME AUTOMATION TECHNOLOGIES

Technology	**Comparison**			
	Missing Sensor Types	***Power Supply***	***Installation***	***Price***
ELV Homematic		Battery	Easy	500€
Moeller XComfort	humidity	Battery /Wired	Difficult (wires)	1250€
Z-Wave	humidity	Battery	Easy	800€
EnOcean		Energy Harvesting	Easy	1550€

2) *Sensor type selection*

An ambient monitoring system for activity recognition should be developed. Therefore ADLs were mapped to specific sensor types and locations to select the necessary sensors (TABLE II). Four ADLs were selected that give most insight into the health state of a person.

For example the ADL Elimination is derived from a motion detector in the rest room in addition to a contact sensor which is placed at the flush handle. Some locations of sensors have to be more specific than others. Especially contact sensors have to be placed on certain objects like a fridge or a closet. Motion sensors should be placed in a spot where the whole room can be supervised. Temperature/humidity sensors can be placed everywhere in the specified room.

TABLE II. SELECTION OF ADLS ACCORDING TO [8] 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
Mobilisation	Motion	All rooms
	Contact	Entrance door
Eating and Drinking	Contact	Cupboard
		Fridge
	Motion	Kitchen

3) *Conclusion*

The limited budget lets us choose from only two sensor systems: Z-Wave and Homematic. Homematic offers a humidity sensor bundled with a temperature sensor and is still 300€ cheaper than Z-Wave. As only Homematic sensors match our requirements especially concerning the price, we didn't conduct any further comparisons concerning robustness and accuracy. In short Homematic sensors are used in the further development of the monitoring system.

C. *Data storage and communication*

To gather the home automation sensor data and the smart meter data an embedded PC unit is integrated. Smart Meter data is read out through a serial connection. Home automation sensors are connected to a sensor gateway that sends the sensor messages via Ethernet and power line communication (PLC) to the embedded PC. The PC is located next to the smart meter, which is usually in the basement of a building. A wireless 3G router is dedicated to transmit the data for further processing to the central database through 3G/GPRS connection.

IV. ASSESSMENT CONCEPT

The monitoring system aggregates activity data from persons living in a household. As ambient sensors are not able to distinguish between persons, single households are the main target audience. More in detail, the participants we are looking for should be at least 65 years old, living on their own, act independently in mobility and should be self sustaining or hourly cared by relatives or a nursing service. As an incentive participants will have the possibility to use in-house emergency systems which are already offered by various health organizations.

The aggregated data from the monitoring system needs a reference to evaluate functionality and plausibility of the activity information. Consequently an assessment concept has to be defined to assure the collection of reference data. Both, sensor and reference data, need to be stored on a central platform to connect both information sources (Fig. 2).

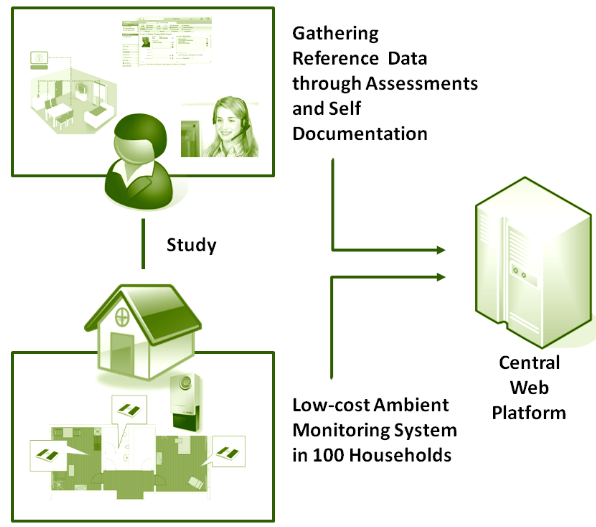

Figure 2. Assessment Concept

A. *Reference data*

The collection of reference information is very important concerning the evaluation of the monitoring system. On a lower level it shows if aggregated data is plausible, e.g. distinguish between inactivity and absence. Through an assessment the state of a participant can be pictured. The abstraction of health states through scores can then be mapped to sensor data. This can be used to find out which information or indicators are hidden in the sensor data.

The assessment is divided into two parts: interviews and self documentation. At the beginning and at the end of the study one on one interviews are conducted. In between those personal talks shortened questionnaires are performed through telephone every month. The timeframe of the study is six months. Additionally a diary is given to the participants for self documentation.

1) *Interviews*

Reference information gathered through one on one interviews or telephone questionnaires can lead to varying assessment quality depending on the inter-rater variability and questionnaire validity. To assure a certain standard different assessment tools were analyzed and compared to our needs.

In the geriatric field and in the nursing environment different assessment tools are available. Among others the following tools are interesting for our application [9]:

- 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 assessment tools is needed. Furthermore these tools were developed from different backgrounds and therefore targeting different professions. We have to critically verify the validity of collected data using those tools. We also have to keep in mind that the assessment is performed by interviewers, which are possibly not familiar with the listed assessment tools and lack the diagnostic capability which is needed to utilize those tools. This means that the assessment should be easy to apply to hereby increase the validity of answers. Also a shortened questionnaire needs to be derived from the assessment. The challenge is to evolve an assessment which meets those requirements.

2) *Self documentation*

Collecting information through diaries is used in many fields e.g. market research to receive specific feedback. In our case we want to collect data through questions about state, health, absence from home and visits from relatives or other people on a daily basis. This information can be used for interviewers to ask more specific questions during the telephone questionnaire. Moreover the information can be used to check sensors for misleading messages e.g. when more than one person is walking through the apartment.

B. Central web platform

To connect the monitoring data with the reference data a central platform for storage is needed. Data from the distributed households and assessment results are brought together.

1) *Requirements*

The goal is to gather data from 100 households. The platform has to be able to process the monitoring data and scale up to 100+ houses. The information stored is very personal. Therefore a pseudonymization has to be implemented and a user authentication is needed. Another requirement is the flexibility of the system. It should be possible to easily implement services which put more intelligence into the processing of the monitoring data.

2) *Central database and visualization*

One part of the central platform is the database for storing data from home automation sensors and the smart meter. Besides that assessment results together with diary entries are mapped to every participant/household.

To provide a certain readability of the raw data, abstractions and visualizations, e.g. graphs, have to be implemented which include also the history of every sensor.

3) *Interface for different target groups*

The web platform needs to be accessed by different groups. To have an overview of the functionality of the monitoring system in every house, a technical administrator needs to have access to the measurement data to gather errors. The interviewer needs to fill in the assessment results, have access to self documentation and the activity information of the participant. Researchers should have access to the database to develop and evaluate new assistive systems and algorithms.

V. EVALUATION OF THE MONITORING SYSTEM

The concept of the assessment showed that this project is focused to evaluate the ambient monitoring system in larger scale. For the evaluation we targeted four steps (Fig. 3). We start with a test of the monitoring system in a living lab environment. This is followed by test installations in non-target group households. In the next step we acquire 10 households of the target audience to start a pretest including assessments. Lastly install the final low-cost monitoring system into 100 houses. Results of the first two steps are already available and summarized in the following subsections.

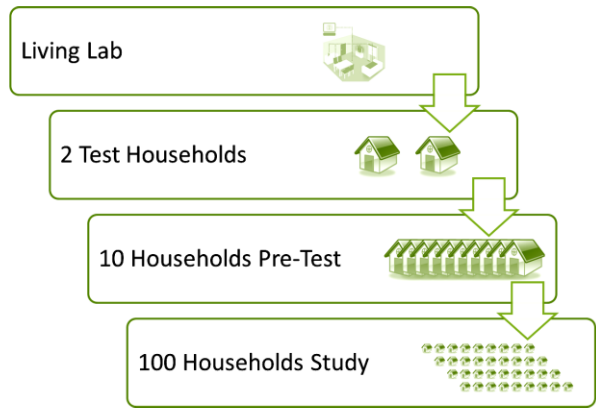

Figure 3. Evaluation Process

A. Living lab test

The FZI Living Lab AAL [10] environment offers the possibility to develop, test and evaluate prototypes, and use cases, like the monitoring system, in a real home environment enabling the integration of end users in an early stage of the project and supporting the implementation of AAL services by offering a wide infrastructure (Fig. 4).

First the behavior of the sensors was tested. Questions concerning frequency of messages, possible errors and installation restrictions were answered. Secondly the recognition of simple activities was tested with each sensor at designated positions. Finally the concept was presented and discussed with a group of nurses.

Figure 4. Modell of Living Lab at FZI

A short summary of conducted tests is now presented.

1) Functional testing

Home automation sensors ship predefined with specific operating modes, e.g. frequency of status messages. We investigated the duration between consecutive messages to know if sensors were still working. If there isn't any activity, messages are sent from the motion and temperature sensor every 2-6 minutes. A contact sensor sends an alive message once a day. A low battery flag is set to advice a change of batteries before the sensors are out of order.

If the study participant moves a sensor from the original position, the anti-tamper protection will recognize the change and sends a warning message.

Furthermore the sensor message includes a counter to identify if messages were not received by the sensor gateway. The sensor gateway itself is sensible to high traffic in the network. Through long-term tests in a company network the sensor gateway got hung up a few times. Only a hard reset could resolve the issue. The monitoring system relies on its own network with comparable low traffic, so it is unusual to get the same error.

Also contact sensors are sensible to metallic surfaces which should be considered when being installed. Spacers can be used to overcome this issue.

2) Activities test

In our test we targeted more specific activities, like traveling time, inactivity, washing and movement in bed, which were not obvious to be recognized by our sensor setup.

The motion detector recognized movement in a room every five seconds. So no exact information about traveling time from one room to another can be calculated, but it is still accurate enough to estimate the mobility of a person.

The opposite of movement, inactivity like sitting on a chair, is not directly measurable. Only through the history and context information a certain activity can be assigned.

Bathing was detected successfully using the humidity sensor. Significant changes in humidity were spotted during showers. In contrast washing at the washbowl couldn't be detected with the humidity sensor. Instead a motion sensor was placed next to the bowl which led to satisfying results.

Another aspect was the accuracy of recognizing a person moving in bed. The conclusion with a sensor, placed at the top of the bed, was that only strong movements are discovered, e.g. getting up from bed. Among other domestic activities, a way of detecting falls is still under investigation.

B. Test households

The ambient monitoring system was evaluated in two non-target group households (Fig. 5). The reliability of the sensor system was tested on a long term basis. The steadiness of the transmission to the central platform was observed. Errors or bottle necks were identified so that the software could be revised.

So far a very high availability of the system could be assured. This makes us confident about the up scaling to 100 houses. Best-practices concerning installation of the sensors were developed. This will lead to faster and more reliable installations.

Figure 5. Examples of Home Automation Sensors Installed in the Test Households

VI. Conclusion and Future Work

A low-cost ambient monitoring system based on smart meter technology and home automation sensors was presented. We described an assessment concept to collect reference information on a central web platform, to offer a standard data set for further data analysis and future developments of AAL-systems and algorithms for ADL recognition. The reference data consists of results from one on one and telephone interviews. In addition a diary is used by the participants for the documentation of everyday occurrences.

The monitoring system needs to pass through different steps of evaluation. First we started with a living lab test setup, where function of sensor was evaluated and then simple activity recognition was validated. In two test households the whole monitoring system was installed and runs on a long term basis to get more experience with the sensors and the central platform.

Next step is the evaluation of the sensor setup and the assessment concept in a trial with 10 households within the target group. After a revision due to possible issues during the pre test, the rollout to 100 households can be started.

Acknowledgment

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