Advanced Technologies and Societal Change

Reiner Wichert
Birgid Eberhardt *Editors*

Ambient Assisted Living

5. AAL-Kongress 2012
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Preface

Due to the changing demographics, residing and being cared in the own familiar environment is becoming the more attractive alternative for an ever increasing portion of the population in contrast to an institutionalized inpatient setting. “Ambient Assisted Living” (AAL) aims at extending the time older people can live in their preferred home environment by increasing their autonomy and assisting them in carrying out activities of daily living, but also by the use of ICT products and the provision of remote services including care services that will assist them to achieve the autonomy, independence and dignity appropriate to their needs and conditions.

Even the concept of AAL has been established now over the last few years and a lot of national and international R&D projects have been funded, we are still at the beginning of a huge paradigm change within intelligent and assistive environments. Despite its tremendous market potential, AAL is still on the cusp of a mainstream break-through. A lack of viable business models is considered almost unanimously to be the greatest market obstacle to a broad implementation of innovative AAL systems.

On the other side the goal of a realization of the AAL vision is impeded by a number of obstacles and problems, for which this conference discusses possible resorts, approaches and recommendations within numerous papers. This volume contains the best scientific papers selected for presentation at the AAL-Kongress 2012 within this year’s focus on technologies in a self-determined life. This congress has the goal to bring together developers, producers, service providers, carriers and end user organisations working in the field of technologies and applications of Ambient Assisted Living and discusses the problems and challenges we have to face in the common years.

To meet these challenges a new series of events has been established in 2008 called AAL-Kongress (Congress for Ambient Assisted Living) with the focus on applications of intelligent assistive systems within the areas of “health & homecare”, “safety & privacy”, “maintenance & housework” und “social environment”. At the second AAL-Kongress 2009 more than 520 participants attended. It focused on use cases to support the manufacturing of products adjusted to the needs of the user. In 2010 the third AAL-Kongress had been organized with close to 600 participants also with the focus on use cases. In 2011 it advanced to the leading congress for AAL with 870 participants.

In 2012 the fifth AAL-Kongress is addressing economical challenges and trendsetting applications on innovative technology. To underline the research priority the research papers have been evaluated more restrictive. 156 papers from 474 authors within 8 countries have been submitted to the AAL-Kongress. After a solid review process 25 papers were accepted to be included in these scientific proceedings of the conference. Three independent reviewers were matched by their expertise area to the topic of each paper.

In closing I would like to thank the 22 reviewers of the Reviewing Committee, the organizers of this event and all of the paper presenters and conference participants who helped to make the AAL-Kongress 2012 a success.

Program Co-Chair for Technical Research Papers
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Contents

Part I:
Sensor Technology

Application-Oriented Fusion and Aggregation of Sensor Data

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Abstract. A glance at the today's research and industry community shows that AAL installations are normally offered as "complete solutions", often including overlapping of almost equal or homogeneous sensors. Thus, redundant sensors are integrated in one single space when purchasing different AAL solutions, leading to an increase of acquisition costs and higher data volume. In order to counteract this problem, we present a method for application-oriented fusion and aggregation of sensor data. Here, the main contribution is a reference model and a semi-automatic approach for the determination of applicability of sensors to predefined AAL applications.

1 Introduction

In specific areas such as home automation, activity recognition, or smart metering, a multitude of sensor and actuator technologies are employed which have different properties, e.g., wireless vs. wired communication, microsystems and terminals, etc. Here, methods for sensor fusion and aggregation have a supporting effect: the combination or junction of sensor data leads to better quality of gathered information in comparison with the consideration of individual devices. In this scope, improvement of information refers to a more stable behavior with perturbations and an increased clearness of statement by means of enhancement of the measurement range and the resolution of measured data [1]. Furthermore, additional information, like characteristic activities of daily living (ADL) for long-term behavior monitoring, can be gathered from the combination of sensor data, which cannot be captured from the single data streams [2][4]. So, main directions of sensor fusion focus on activity recognition, context recognition, or personal identification.

A consideration of the research community shows that, from a methodological point of view, especially the area of sensor technology for activity and context recognition is not sufficiently understood and supported. Current publications on AAL applications indicate that sensor data is often integrated in an application or system in a proprietary way (tailored to specific requirements) or, if basic interfaces are defined, no detailed specification of sensor types and data formats are provided. Common users and deployers of respective systems, for instance programmers, system integrators or engineers still rely on ad hoc defined interfaces and methods of data processing. Thus, AAL solutions or installations are normally offered as complete packages consisting of a collection of sensors (and actors) along with software supplying complex behavior. As these are tailored for specific needs it stands to reason that multiple systems may be required within an AAL space. In essence, each particular need, i.e. each application, requires the acquisition of an entire AAL package. Since the physical devices are typically fairly basic and straightforward in their behavior, this may lead to redundancy whenever multiple solutions are employed. This duplication leads to higher costs (both initial and running) caused by redundant purchase, as well as an increased maintenance. Additionally, data overhead is increased, which may result in excessive wiring or, if wireless technology is used, lead to bandwidth problems and increased interference.

In this work, we aim at reducing the overlap in hardware devices (sensors and actuators) using a semi-automatic approach. The main goal can be described as follows: Given an AAL platform and an application selected by the user, the system is to provide feedback on whether the application can be realized with the devices at hand. If no matches are identified, the system is to signalize which devices need to be bought additionally. The groundwork for solving this problem was laid with the conception of AAL interoperability platforms such as Continua, OASIS and universAAL. Basically, they allow individual sensors and actuators to be replaced by semantically equivalent devices to ensure that the information and services provided by sensors and actuators from the physical devices are in a sense decoupled from the physical devices. Here, we show that, given a suitable data model, it is possible to extend this approach to higher abstraction levels.

The remainder of this paper is organized as followed. First we present related work with respect to the identification of sensors and actuators based on a predefined application. Second, we present the conceptual model for application-oriented fusion and aggregation of sensor data, generally consisting of a specific data model and reference model as well as a workflow-based description of a three-step semi-automatic approach. Third, we show how this approach can be employed in the scope of activity recognition. Finally, we recap the results and show venues for further research.

2 Related Work

There are several approaches to model and implement a universal AAL platform to ensure interoperability between different sets of hard- and software components. Here, we particularly need to consider approaches which deal with the junction of sensor data in a common context, and allow the retrieval of sensor types that are applicable in specific scenarios. Regarding this issue, only a few work concerning sensor fusion and aggregation can be identified.

Within the AAL research community, the OASIS project deserved mention for introducing the concept called hyper-ontology which is used in conjunction with ontology alignment to map applications to their domains [5].

Outside of AAL the Open Geospatial Consortium's (OGC) Sensor Web Enablement standard offers sensor fusion with an emphasis on geospatial data.[6] It relies on the OpenGIS Sensor Model Language (SensorML) which describes high level processes as partitioned process chains. The standard has an extensive system for describing each constituent semantically, particularly its input, output, and the underlying physical laws or algorithm that governs its inner workings [7].

3 A Conceptual Model for Application-Oriented Fusion and Aggregation of Sensor Data

In this section, we introduce a conceptual solution for application-oriented fusion and aggregation of sensor data. First, we present an overview of the approach and substantiate its feasibility in short. Then we discuss the data and reference model for a three-step semi-automatic approach.

3.1 Overview

The concept presented herein relies on the existing AAL platform universAAL [10]. This choice is meant to be representative for other state-of-the-art AAL systems: First, it comprises a data model based on the RDF standard [11] for the purpose of information exchange. Second, we expect resources in the AAL space - in both the physical and virtual realms - to be modeled by means of an ontology, e.g., using OWL. Here, OWL-based messages ("context events") describing the current state of (a part) of the AAL space ("context") can be provided as an RDF statement.

In the user-centric view, an application is a black box that provides a certain set of functionality. In contrast, we concentrate on the context the application operates in and the services it needs to call. We call this the *signature* of the application.

Observe that contexts can be atomic, given at sensor level, or derived via sensor fusion and algorithmic reasoning. A similar statement can be made for services. In the atomic case, the software would be dependent on the given hardware, in the second case however the application would be agnostic to the physical devices. In its simplest form, this corresponds to a common approach in IT systems to achieve interoperability: software wrappers and drivers abstract over a homogenous set of software and hardware respectively. In general, we need to abstract a heterogeneous set of a large number of possible setups with many-to-many relationships between the resources and their abstraction. Figure 1 outlines an abstract example showing one layer of abstraction over the device context. In reverse direction, given an arbitrary context, we can check if it can be broken down into simpler ones. We call this action a *decomposition*.

Figure 2 illustrates this concept. The main idea is to describe the application in the most general terms and consider possible decompositions. This means that reasoning and sensor fusion components are pulled from the applications to gain a greater independence from low-level details. Similarly, a service can invoke another service. Accordingly, there are specific dependencies between different services.

The approach presented herein is semi-automatic in the sense that human input is used to resolve ambiguities that may arise in certain situations. To give an example, Let us assume that we want to monitor a person, raising an alarm when he or she falls. To realize this functionality, we can either fit the client's body or the floors in his home with sensors. A priori, both options are equally valid. This represents a real choice for the user.

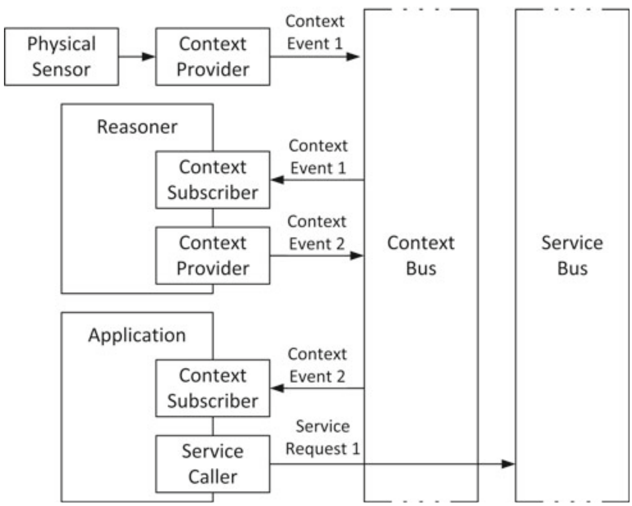

Fig. 1. Data Flow in a universAAL Application

3.2 Feasability

As discussed in the introduction, the current paradigm is having a complete system of soft- and hardware for every application. The user determines which applications he or she requires and, accordingly, acquires packages that provide the specific functionalities. Implicitly, we get a mapping from the sensors, actuators, and governing software to the provided features. This information can also explicitly be provided in external repositories by manufacturers and developers, various stakeholders, such as health care staff or patient groups, and third parties, such as research groups.[1]

[1] cf. OASIS hyper-ontology concept in [5].

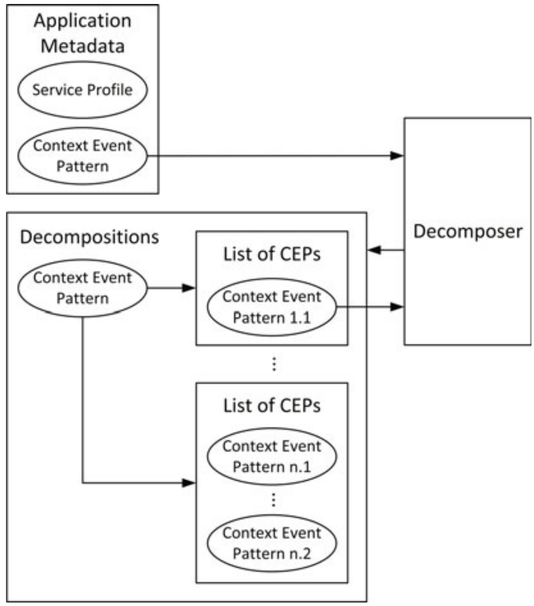

Fig. 2. Data Flow in Decomposition

3.3 Data Model

Since this project builds upon the universAAL platform, we inherit its data model. As already mentioned in Section 3.1, universAAL is meant to be representative for state-of-the art AAL platforms. In essence, we operate on an OWL ontology and capitalize on the RDF model. These standards ensure that the concept presented in this paper can be ported to support alternative platforms. First, we recap the most important facts about the data model. Then we present the metadata model for applications built upon the models already given.

3.3.1 Context and Services

UniversAAL uses two different buses for communication between its components. The context bus is event-based and used to provide data. The service bus is request-based and used to access functionality. Recall that context events are given as RDF statements. They are specified via *context event patterns*, essentially lists of OWL restrictions over its properties (i.e. subject, predicate, and object). UniversAAL has three different types of resources that can provide a context: gauges, controllers, and reasoners. A gauge is a wrapper for a physical sensor, an abstraction layer that transforms its raw output into a context event. Similarly controllers abstract over actuators and create an event based on the change it facilitated. Finally reasoners infer context based on other context events. Service metadata is similarly encapsulated as service profiles (cf. [12]). Service profiles characterize a service with two basic types of information: "What is the service for" and "how it can be utilized" [12]. Here, we concentrate on sensors and accordingly on context event patterns. Whenever possible we provide the corresponding procedure for handling services.

3.3.2 Ontologies

Every object in universAAL, both physical and virtual, is modeled as an RDF resource or a subclass thereof. Each resource within an AAL space has a unique identifier. To capture the complex relations and interactions between the components, ontologies are employed. The first trait ensures that both context event patterns and service profiles are well-defined, if used properly. The second one allows us to qualify arbitrarily intricate sets of resources via restrictions.

3.3.3 Application Metadata

We characterize an application by its signature as defined in Section 3.1. That is, it is stored as a list of context event patterns and service profiles. By using the same data structure as the AAL platform, we ensure that we can easily check against the state of the AAL space and the low level services it provides. Given that ultimately we rely on the common standards RDF and OWL, it is possible in principle to translate between different AAL platforms that fulfill the minimal set of conditions given in Section 3.1.

3.3.4 Decompositions and Dependencies

The concept of decompositions as introduced in Section 3.1 entails a one-to-many relationship between a higher-level context and a list of lower-level contexts. In the case of contexts, this description closely related to the concept of the reasoner which takes lower-level concepts to compute a high-level one; both follow from the underlying concept of abstraction. Note, however, that the abstraction level is not a formally defined property. While a tree-like structure arises naturally when we consider a single context by itself, as a whole we can only characterize the relations as a directed graph. Therefore, care must be taken to avoid or detect cycles. The same is the case for resolving dependencies between services. These arise when a service invokes other services.

3.4 Reference Model

The concept presented here can be divided into three different parts. In the first one we discuss the required data stores. Then we present architectural components which set up the reference model. Finally, we explain a three-step semi-automatic process, examining a respective workflow in detail.

3.4.1 Data Stores

As mentioned in Section 3.3.3, we need to store application signatures. We call the required data store the Application Database (see Figure 3c). Here we also store a human readable string for identification. The Application Database can be realized as a local database. Additionally, external repositories are required for decompositions of contexts and dependencies between services, and ontologies to retrieve mappings from context event patterns and service profiles to physical devices and accompanying software. We presume the existence of a multitude of repositories, reflecting diversity in devices and the number of their manufacturers.

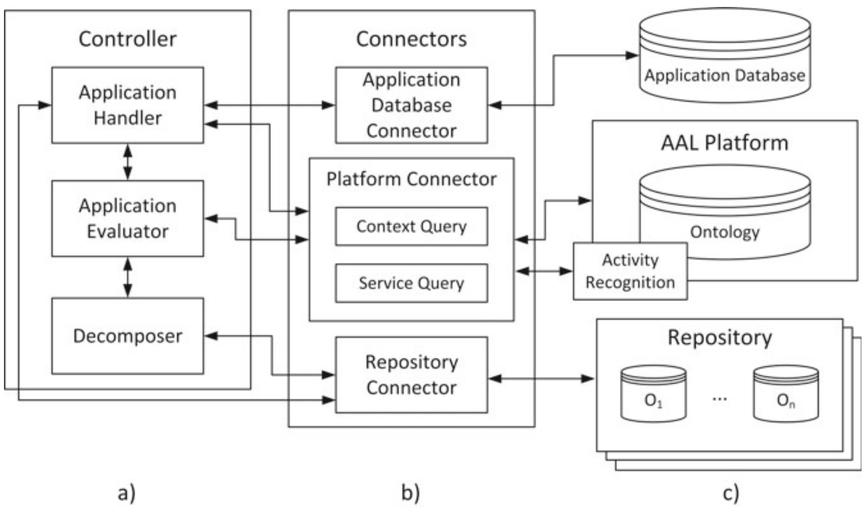

Fig. 3. Reference Model

3.4.2 Components

At the lowest level there are so called Connector components, namely Platform Connector, Application Database Connector, and Repository Connector (see Figure 3b). The Platform Connector comprises interfaces that enable the communication with the AAL platform we operate on. First and, foremost these components are responsible for making inquiries about the build-up and the state of the AAL space. Additionally, we have connectors to the external repositories and to an application database that holds the applications the user is interested, both introduced in the previous section. On the next level we have the Controller layer, which consists of Application Handler, Application Evaluator, and Decomposer. These components are used to handle the input from the user and the output of the Connector components (see Figure 3a).

In this section, we described the basic components included in the reference model in abstract terms. The specific functions of these components are elucidated in the following section by means of the workflow associated with a three-step semi-automatic process.

3.4.3 Workflow

On the basis of a specific workflow we demonstrate how application-oriented sensor data fusion and aggregation is realized by the presented reference model in a three-step semi-automatic process. Given an application, the first step is to check for the existence of the contexts and services that are required for it to run. If a resource is missing external repositories are consulted. In the final step the user receives a list of options of devices and software that would allow him to employ the application in question. In this section we discuss the individual roles of the components introduced above in order to describe how to accomplish the tasks explained below. Figure 4 shows the corresponding data flow.

From an application-centric point of view the following tasks have to be considered: fetching an application from the Application Database (marked with dashed arrows in Figure 4), creating new applications (marked with white arrows in Figure 4), and evaluating applications to determine whether they can be employed within the current AAL set-up (marked with black arrows in Figure 4).

The Controller layer, as mentioned above, handles all the communication between the user and the presented system, hiding the low-level data exchange with the AAL platform and the data stores. The Application Handler is the key component for user interaction. First, it loads a list of the existing applications from the Application Database using the according connector component. Second, it can be used to create new applications by combining existing resources in the AAL space. To accomplish this, the Application Handler employs the Platform Connector and the Repository Connector to execute queries over the existing local resources and external ontologies respectively (cf. Section 3.4.1). The user is provided with a list of possible contexts and services from which a subset can be chosen and aggregated. The new application can now be stored in the Application Database.

However, before it can be deployed, we have to ensure that the required resources are available. By definition these are fully specified by the Application signature (see Section 3.3.3). To check the signature against the AAL setup, the application metadata is forwarded to the Application Evaluator. This component performs queries for the context event patterns and service profiles using the appropriate sub-components of the Platform Connector. If every signature entry is well matched with a corresponding resource in the AAL space, a positive result is returned to the Application Handler.

If the result is negative, i.e., not every signature fits to a resource, the unmatched resources are passed to the Decomposer component in order to start the decomposing process (see Figure 2). As mentioned in Section 3.3.4, higher-level context events are the result of sensor fusion or aggregation while services form dependencies. In the latter case, missing services are searched for in external repositories via the Repository Connector using the associated service profile as parameter. Depending on the success of the query, the Decomposer either returns a list of possible candidates to the Application Evaluator or reports the negative result. In the case of contexts, a more differentiated approach is required. First let us consider the simplest instances. A context may be entirely missing from the repositories if it is malformed or suitable soft- and hardware has not yet been developed or released to the public. Here, we simply report a negative result to the Application Evaluator. Another possibility would be having an atomic context. In this case, the context event pattern can be matched to devices which provide the associated context events. This list is simply returned to the Application Evaluator.

Recall however, that in general there is a one-to-many relationship between a context and possible decompositions. The list of decompositions can be presented to the Application Evaluator. In this case, each entry in each decomposition list could in principle again necessitate a decomposition process. Since the underlying data structure is recursive, in theory we have to rely on the repository owners to make sure the queries terminate properly. In practice, a recursion depth limit should be implemented along with cycle detection.

After this recursive fusion and fission process, the Application Handler should get the message about which devices can or must be integrated in order to realize the given application. Thus the Application Handler is able to give user-feedback about the devices that have to be purchased.

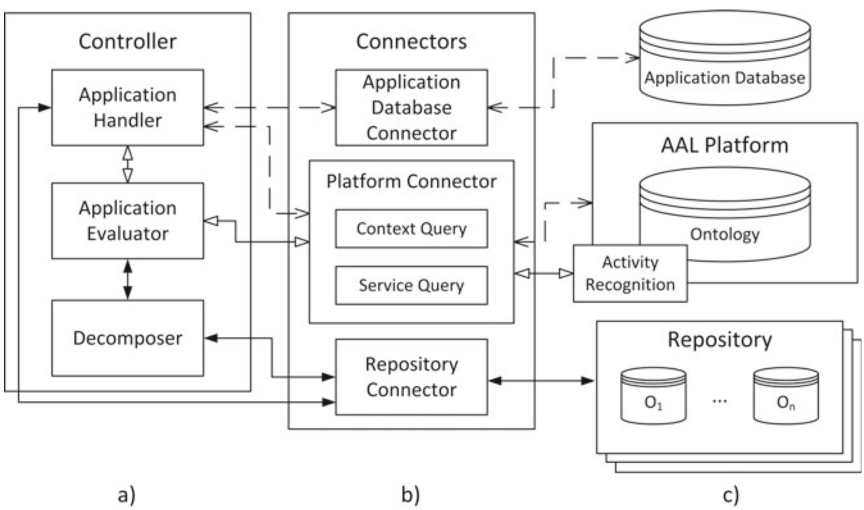

Fig. 4. Reference Model with Data Flow

4 Fusion and Aggregation for Activity Recognition

In the previous Section, we presented a model which enables the determination of adequate sensors based on a predefined AAL application. Given the assignment of sensors to applications, fusion and aggregation can be performed by means of specific reasoning components.

As already mentioned in Section 1, sensor (context) events can be joined to composed events through fusion and aggregation and, further on, to higher-level activities. With respect to the presented reference model, an example for a connected component (see Figure 3c) is the Event-based Activity Recognition and Reaction System (EARS) which has been initially developed in the context of the EMERGE project [8].

The major goal of this component is to identify specific patterns at the continuous event stream. This will be done on-the-fly, so that it is possible to trigger an adequate reaction if necessary. Typical event patterns from interest are the so called (instrumental) Activities of Daily Living (ADL) [3] for behavior monitoring on a long-term view. The challenge is that the patterns of ADLs can be very different in their structure like sequential or fuzzy or a mixture. Additionally the activities can be individually performed and may overlap.

Another requirement for the EARS-framework was that learning of the activities should be avoided because of its obtrusiveness. The general idea is that complex patterns will be split into several small patterns with a simple structure, e.g. the sequential sub-activity "fridge usage" is again a weighted indicator for the fuzzy ADL "Preparation of Meal". The rule format allows the creation of self-contained specialized agents for pattern recognition (more information see [9]). Based on the experiences, the set of agents has been increased, so that other functionalities (in special with focus on "reaction") are covered, too. The agent set is not limited, so that agents with not covered functionalities can be added easily.

The communication of the agents is handled internally, but the communication with the AAL-System is made in the publish-/subscribe-style like the "reasoner" shown in Figure 1.

5 Conclusion and Future Work

We examined the problem of redundancy in the use of multiple concurrent AAL solutions. We have shown that it is possible to conduct sensor data fusion and aggregation on an AAL system, at which a minimal set of sensors and actuators can be employed, exemplifying this with the application on the universAAL platform.

Currently, in the scope of the BMBF-funded project *OptimAAL*, a prototype operating on the universAAL platform is being developed according to the concept we introduced in Section 3. The prototype will first be tested in a laboratory setting that contains a mimicked home. Following a successful test, a field study taking place in real apartments for the elderly is being prepared for validation of the presented approach. The next step in improving the presented system is to take Quality of Service (QoS) into account to rate setups. Other cost functions such as acquisition costs, running costs, space and volume taken up by the devices are possible candidates. Given a user preference, these considerations could increase the automation in the semi-automatic approach.

While so far we have only taken technical restraints into account, it is evident that non-technical restraints, arising from personal, cultural or medical conditions, can render a particular setup unacceptable to a user. Preliminary feedback has shown for instance, that audio signals might be unsuitable for alerting the elderly because of diminished hearing capabilities. Identifying and incorporating these additional constraints requires expertise in a number of different disciplines.

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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)

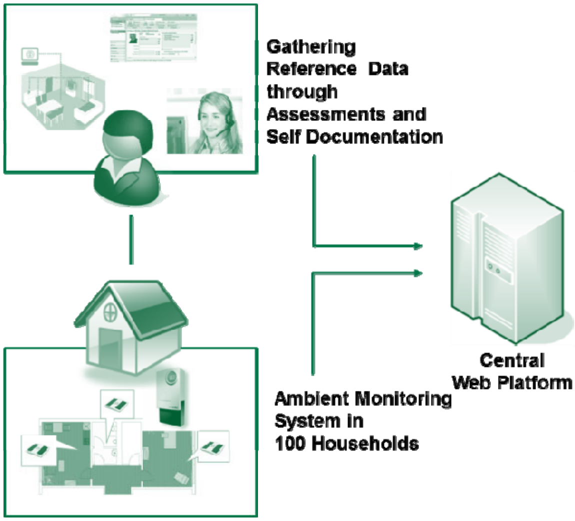

Fig. 1. Study Concept

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.

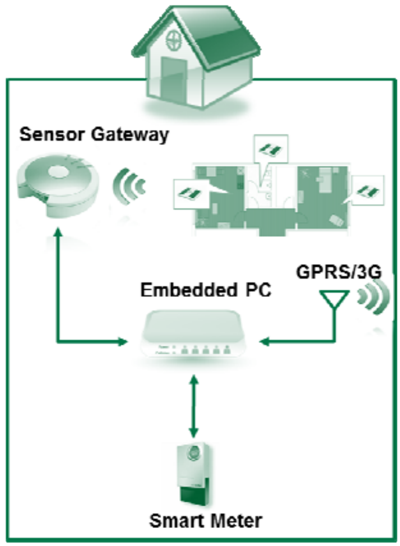

Fig. 2. Technical Concept of the Monitoring System

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.

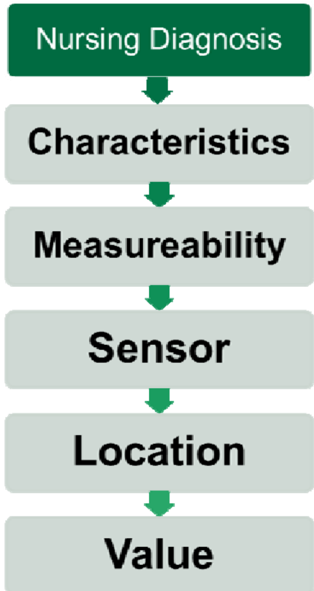

Fig. 3. Sensors derived from Nursing Diagnoses

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.

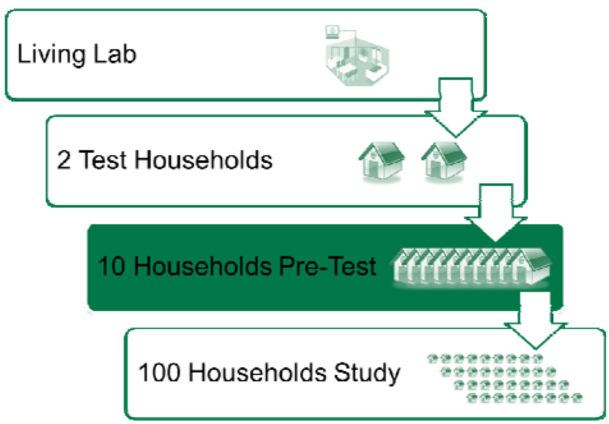

Fig. 4. Evaluation Process

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)	> 1 year
	2-6 min (without motion)	
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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Automatic Recognition of Emergencies with the Help of Optical and Acoustic Sensors

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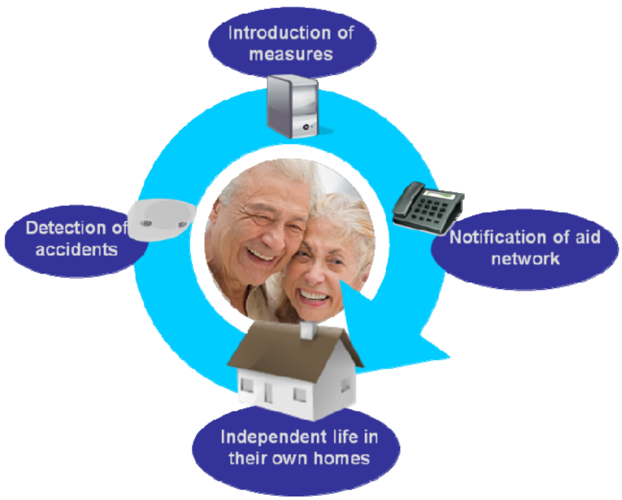

Abstract. Within this article a sensor-based safety system is presented which enables an automatic recognition of emergency situations in every day domestic ambiance and triggers autonomously alerting measures without explicit user interaction. The development is performed in the research project sens@home [1] which is funded by BMBF (German Federal Ministry of Education and Research). Within the scope of this project a requirements' analysis had been accomplished first by doing workshops, interviews and questionnaires with potential user groups. Considering the determined demands and requirements, potential adequate sensors have been selected. Here, the main focus was on reasonably priced and contactless sensors which assure a quick recognition. To meet these demands acoustic and optical 3D sensors turned out to be a promising solution. In the second step, by means of practical laboratory experiments, appropriate evaluation algorithms have been developed in order to combine data from several sensors and to elaborate scene-based accident recognition. The advantage of this solution based on low priced optical and acoustic sensors is, that typical emergencies can be detected automatically within a few seconds and there is neither a need for any physical contact or interaction of its users nor any expensive alterations as it can be build in cheaply in every kind of living space. In addition, a large part of the evaluation can already be accomplished in the sensor whereby no data will have to be saved or transmitted.

1 Introduction

The Federal Republic of Germany and many industrial countries are in the process of demographic aging, whereby the number of persons in need of care will increase in the next few years.

Many solitary people of the elderly generation will live self-determined in their own living environment as long as possible. Up to 90% of their time they stay in their living environment, as their centre of life [2]. However, the risk to get into a dangerous situation increases in the older age. Apart from dangerous situations, there is a risk that an injured person won't be able to get up again or to alarm someone. This could lead to uncertainty and fear and might also force elderly people to take themselves in medical attendance.

One option to improve safety in the living environment is the AAL technique. Technical assistance systems for detection of accidents and automatic emergency calls offer a great chance to letting grow the sense of security for the living environment.

2 State of the Art

An alternative to a constant medical attendance are technical solutions for automated emergency detection, though there are only few appropriate and widespread market solutions. Technical solutions can be divided in two categories. On the one hand the techniques which can be worn directly on the body and on the other hand structural solutions which are integrated in the living room.

2.1 Wearable Sensors

The best known of the category "wearable sensors" is the home emergency call which has already been established as a central security instrument [3]. This kind of emergency call has one disadvantage: it has to be worn permanently and operated actively. This has a high impact on the efficiency. In addition there is no protection against false alarms.

Furthermore, there is a large number of miniaturised wearable sensors for emergency detection - for example sensors for observations of vital functions [4] or speedup sensors to detect a fall [5]. Such miniaturised wearable sensors need a periodical interaction of the bearer (e. g. fasten and remove, configuration, recharge) and they'll only work if they are still in reach. This means a high limitation regarding functionality and comfort.

2.1.1 Embedded Sensors and Intelligent Home

Another solution for emergency detection will be sensors which are directly integrated in the living room. The most known representatives of these sensors are the automatic interaction of light and motion detector or the door- window and shutter control. With the help of suchlike sensor data one could create an action profile and in case of a major deviation the conclusion is an emergency situation [6]. Another possibility is to integrate sensors into the floor [7] and the wall [8]. They are much more expensive but allow a precise situation analysis. The common disadvantage of these opportunities is the structural and financial investment which is the major obstacle and above all the integration in housing stocks.

The state of the art shows that the automated emergency detection has to be worn and operated actively or the installation is too complex and expensive. Desirable is a security system which could be installed in every kind of living room in a cheap way where no interaction of the user is required. One solution of such a system is described below.

3 Determination of System Requirements

This paragraph describes the determination of conditions for the planned emergency and security system. In this section besides technical boundary conditions, the focus is on the determination of wishes and requirements of potential users.

3.1 Survey of Potential Users

In addition to the boundary conditions of AAl technologies the user's acceptance and the satisfaction is important. On this account several potential users, practitioners and experts are involved in the requirement analysis first. The aim of the requirement analysis is no representative study. In fact ideas, suggestions and critics for the planned technical development are to be summarised. For this reason, it had been necessary first resolving how to gain knowledge about the ideas of elderly people and their relatives concerning technical auxiliary systems.

Therefore, the solutions from the BMBF accompanying research "user dependant innovation barriers in the area of age-appropriate assistant systems" [9] provide and are used as a basis. The focuses of the requirement analysis were creative groups. Here, during various events ideas and performances for security systems were demanded and developed. Furthermore guideline based interviews were conducted as well as questionnaires were handed out to the participants.

When selecting the participants, it was essential that different regional conditions are covered as well as users from rural and urban areas. In addition to the primary users with and without the need of support as well as the family members were involved in the survey. Furthermore, experts and professionals from social care services, assisted living and house emergency call were invited to the creative group. In the following paragraph, the methods and the derived results are discussed.

3.1.1 Guideline Based Interviews

The interview was conducted by employees of the elderly care BruderhausDiakonie in the domesticity of the participants. Here, general questions in context to the living situation and the activities in daily life were questioned at the beginning, after that questions about the need of support and finally questions in relation to technical equipment as a support in older age were asked.

In the interview more than 24 participants were questioned and the following statements were defined:

- Many of the surveyed persons had already been in a sudden need of help once and most of them get assistance from relatives or care services.
- Security is a basic need for elderly people when living by themselves. The fear of falling, dizziness or physical infirmity is widespread. As a remedy the interviewees would like an improved emergency call or an uncomplicated alternative to call for help.
- The majority regarded the transfer of health relevant data to a confidant like a doctor as useful.
- Often named technical comfort functions are the camera picture in front of the entry door, the simple control of windows, shutters and electrical equipment, intelligent refrigerators as well as memory function for medicine.
- An outright majority of the surveyed persons believe that technical assistance systems are especially useful for people who live alone and are restricted physically.
- With regard to the costs for the elderly it is difficult to imagine how much special function is worth for them. Unique costs up to 1000 euro are considered as unproblematic for the majority of the surveyed.
- Within automated accident detection system the most important fact of the interviewees is that it has to work in each room and it must be possible to integrate it in every kind of living room.

3.1.2 Creative Group

The requirement analysis carried out with the help of creative methods the so called Walt Disney Method was chosen [9]. This method is used for the development of creative and realistic ideas for products and services that is why it is suitable for requirement analysis. In this method, the participants are divided in three groups in order to develop various requirements and criteria from different points of views. The first group called “dreamer” develop ideas detached from the feasibility. The second group “realists” think of the realisation steps. The third group “critics” have to estimate the advantages and disadvantages. Within this method, the questions will be explained by a moderator. The participant develops ideas that have to be discussed in the group. After a time set the participants change roles until everyone has taken part in every kind of role.

Within the creative group 65 persons have been involved as participants. The gist of the various participants could be summarised as follows:

Technology

- The people want as little contact as possible to the technology, they want to operate it as little as possible and if an active control is necessary then by using a simple language, gestures or a few buttons.
- The user must have the final control of the system and the option to switch it off (emergency stop).
- The system has to be reliable and must work without active control or contact and the users must have the opportunities to draw attention to themselves (e.g. by cries for help)
- The system is not allowed to stigmatise. An inconspicuous design integrated into the home is the claim.
- The system should be suitable for people who suffer from e.g. dementia.
- Minor assistance functions in relation to comfort would sometimes be desirable, e.g. shutter control or picture / signals in front of the entry door.
- It must be documented who installs the equipment, services and how the contact is established between users and the technology.

Financing

- The system must be affordable (price order of magnitude of living room furniture).
- The pricing is very important to consider, in case of doubt the functionality must be reduced or a modular design has to be found.
- A cost model is to be achieved which combines private, health and social service financing.
- The briefing and training for the user of the system is essential and must be included in the price.

Privacy / Ethics

- The used technology will be applied only as a supplement and does not replace humans.
- The system must not lead its users to convenience or restricted autonomy.
- The used technology is not allowed to enable externals to monitor the user.
- The system must not frighten its users or spread uncertainty.

3.2 Requirements for the Accident Detection System

By reason of the survey as well as the general considerations from the technical boundaries the following requirements for the accident detection system are defined:

Integration

- Rapid and simple installation in every kind of living room without building measures.
- Wireless connection and no additional wiring (with the exception of the necessary electrical power supply in the location).

Accident detection

- Sensors which are worn on the body or are actively used must be excluded.
- Rapid detection of emergencies (less than 10 seconds).
- Hardly any false alarms and the possibility of reinsurance if there is a real emergency.

Operation

- The system must not be operated or configured by the user.
- Communication with the system (e.g. reinsurance whether an emergency exists) with simple voice control.

Privacy and ethics

- Preprocessing of the date directly in the sensors so that no raw data is transferred.
- Data is not stored.
- The automatic emergency call is the only interface with outside. No other data is leaving the apartment.

Other

- Affordability (total costs at maximum 5000 Euro per 3 room apartment, leasing models up to 1000 Euro per month).
- Scalable system (i.e. unlimited expandability to other sensors and comfort features).

4 Technical Implementation

This section describes the technical implementation of the accident detection system. This initially involves the selection of suitable sensors as well as software technical realisation of the system design.

To meet the requirements, sensors were omitted which must be actively controlled or worn on the body. For this reason sensors attached to clothes, wristbands for fall or vital function monitoring as well as classic emergency buttons are rejected. Furthermore, the sensors have to be easily integrated into the living room and must recognise emergencies within a few seconds. Because of this, solutions based on comprehensive home automations are also excluded. By reason of the profile of requirements from the technical view optical and acoustic sensors are best suited. A combination of these sensors in a simple box offers a promising solution in terms of recognition, price and installability in all living environments. With such sensors concerning such potential solutions one has to focus on the data security and acceptance exceedingly.

4.1 Selection of Potential Sensors

Within the project different sensors technologies are analysed regarding their suitability. This should be, in addition to the defined requirements, the following scenarios for accident detection reliably identified and distinguished from non-hazardous everyday situations:

- Recognition of cries of the person (who lives in the apartment) in the living room.
- Dynamic recognition and tracking of the person despite occlusion e.g. furniture.
- Recognition of falls and interpretation of the situation after going down to the floor.

For the recognition of cries for help room microphones offer a great potential. Special risk areas such as the bed or the sofa can also be monitored separately with directional microphones.

For a robust recognition of a person and the conclusion of possible accidents, robust data is required. Optical sensors offer a great potential, because they are relatively inexpensive, easy to install and operate without contact. Optical 2-D sensors are not appropriate here; as they are too susceptible to lightening changes and shadows. Thermal imaging cameras would provide robust data but are too expensive that is why this sensor concept is not an option. Thus, sensors for 3-D imaging have the greatest potential for such an accident detection system [10]. Laser scanners for required coverage are too large and too expensive. Time of flight sensors are good in size but are also still too expensive. For the principle of a band projection system with the KINECT system a low cost 3-D sensor with a high data quality was developed, but these sensors have a high weakness in the compartment cover, range scales and ambient light influence. The most cost effective solution with acceptable data quality is therefore the stereo video principle. Since technological progress in the fields of the sensors technologies is progressing very quickly, one has to make sure when developing algorithms, that they are independent from the sensors. That's why the evaluation is not in the picture which is different in each of the named sensor principles but in the 3-D point clouds, which can be calculated independently from the sensor.

Within the investigation results other sensor concepts have been discarded as inadequate to meet the requirements because they either do not provide a sufficient data quality (indirect sensors such as motion sensors), could only get integrated very costly to existing dwellings (sensors in the floor or the wall) or are too expensive or must be taken into active (emergency button, sensor wristbands or sensors attached to clothes). However, the evaluation system was built modularly so that the sensor principles are retrofitted.

4.2 Systemdesign

The accident detection system basically consists of two main elements: First of all, there is the sensor unit which records and processes the data. Secondly, the evaluation unit which merges the data, evaluates the scene in a few seconds and sends automatically an alarm in case of emergency.

The sensors required for automatic accident detection are integrated in a so called "sensor box" which is similar to a smoke detector, preferably un-noticeable and capable of being integrated in every kind of living environment.

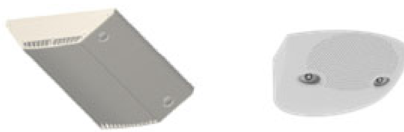

Fig. 1. Possible construction of sensor boxes

The only cabling required is electrical power. In the sensor box next to the optical and acoustic sensors an evaluation system is integrated which preprocesses and analyses the already obtained sensor data. As the basis of the accident detection, some parameters such as the focus of a person or recognised cries are calculated. Since these calculations will be placed directly in the sensor box, it is ensured that no raw data, pictures or video sequences will leave the sensor which is important for privacy and acceptance. Only a few parameters for robust accident detection will be sent to an overall evaluation unit.

For robust accident detection, only a few parameters will be sent to a supervisory master computer which is installed in the apartment. Apart from that no other image data is required for accident detection. Only a phone-based alarm signal serves as an interface between emergency calls in the apartment and the outside.

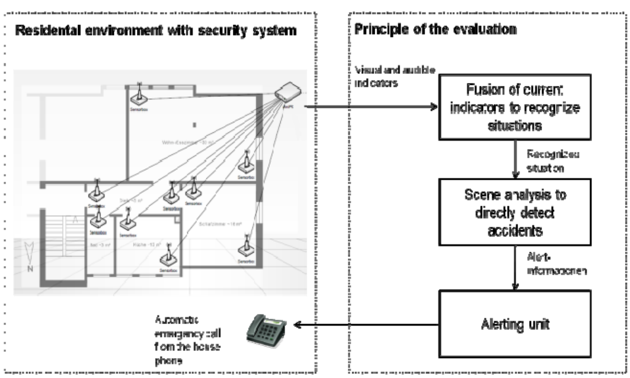

Fig. 2. Principle of accident detection system

5 Evaluation Principle of Accident Detection

The following section describes the evaluation algorithm of the sensor data, the calculated parameters for accident detection, the criteria according to which automatic alerting takes place and the avoidance of false alarms.

5.1 Optical Evaluation

The evaluation of optical data takes place directly in the evaluation unit of the sensor box. Here, 3-D point clouds will be calculated first. So, the evaluation is principally independent of the sensor [11]. Due to dynamic background segmentation, people are detected automatically in the 3-D point clouds. With the people's outline, principal axes and focus are calculated. So, a principal position of the person in the room is provided. The height of the centre of gravity gives information about whether the person is standing, sitting or lying on the floor. Moreover, the changed height allows a statement whether the person went unusually fast or unusually slow to the floor. The parameters can be calculated very fast and robustly – a basis for automatic accident detection.

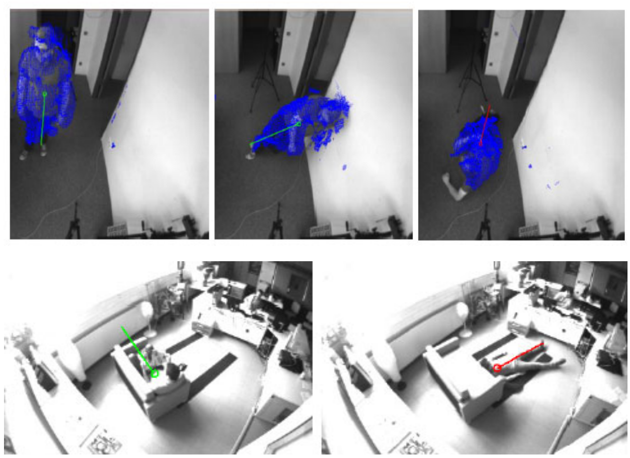

Fig. 3. 3-D point cloud and center of a detected person in typical situations (standing, leaning against the wall, exposed lying, lying on furniture, lying in front of furniture)

5.2 Acoustic Evaluation

The acoustic evaluation based on Hidden-Markov-Models is used for detection of typical screaming, especially crying for help [12]. Here, the noise is recorded in the sensor box and suspicious sound sections evaluated. Hereby, the probability of an existing cry for help is calculated as a parameter for supervisory evaluation. Since acoustic sensors are susceptible through ambient noises, the acoustic parameters are mainly used additionally in order to increase the robustness of the overall system.

5.3 Dynamic Scene Analysis

In order to detect emergencies based on falls, a scene-based approach has been chosen. Here, it is analysed how fast the person falls and how he/she reacts after falling to the ground. If the person remains without moving or cries for help, an alarm will be sent off immediately. But if the person gets up promptly no alarm will be sent off.

The duration regulated by the evaluation system can send off an alarm but depends on the speed with which the person fell down, the intensity of the person's movement as well as further accident indicators based on noises e.g. screaming. If a person goes to the floor quickly and remains motionless or cries for help, an alarm will be sent off immediately. If the person goes down slowly and remains in a crouch, no alarm is sent off but further potential indications for an accident will be analysed.

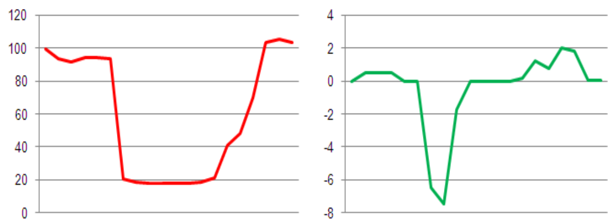

Fig. 4. Analysis of the current centre of gravity height of the person (right) and the speed of the changing height (left)

5.4 Progressive Alarming

Despite a detailed scene analysis, false alarms cannot be excluded. Many everyday situations can be similar to an emergency situation.

Therefore, the system provides a progressive alarm system. After every detected accident suspicion a control call takes place. If the person answers the call, the alarm will be cancelled. If the person is not able to answer the automatic call, a major accident probability is given. Then, a list of deposited phone numbers will be contacted. Apart from relatives and neighbours, social or emergency services can be contacted. Due to progressive alarming false alarms can be minimised for emergency services.

5.5 Evaluation of the System

In order to evaluate the functions of the implemented system regarding the false alarm rate and the reliability of the detection of falling, a data basis with over 100 situations of 16 test persons has been set up. They were asked to perform natural movements and activities in a realistic environment (furnished room with daylight) which could be mixed up with the falling of a person. The following situations were tested: Lying on a sofa or resting on the floor e.g. for cleaning it. Furthermore, the test persons were asked to simulate fainting without stated conditions. Besides, all the steps of sending off the alarm were tested: the phone call in the room had to be answered or ignored by the particular test person. The test person got informed in advance that an automatic voice asks how the test person feels. No additional instructions were made.

The results can be summarised as follows: The person detection failed in two cases because of the accuracy of the used 3D sensor. Those two test persons have a slim shape and could not be recognized when lying horizontally. This problem was solved with modified calibration of the sensor. Furthermore, the evaluation software was extended in such a way that disappearance of a person in the room (not near doors) has been evaluated as a dangerous inactivity. A control call will be initiated then.

Alltogether, only one false alarm was sent off after the speech recognition misinterpreted the reply of the test person. In real life, this would only have caused an unnecessary call to the first person in the contact list.

6 Summary and Outlook

This paper describes a novel sensor-based security system for the automatic detection of accidents which is being developed in the project sens@home. Therefore, first appropriate sensors and the system design were developed under the aspect of the target group defined requirements.

The required optical and acoustic sensors and the associated evaluation units have been built into these so-called sensor boxes which are able to detect reliably emergency indicators such as falls or cries in the home environment.

Because the evaluation units are directly integrated into the sensor boxes, the sensor data is not stored or transferred which guarantees privacy and data protection. For the final scene, one accident detection analysis is performed over a short period by which appropriate measures are taken. In order to minimize false alerts, a progressive alarm system has been developed which performs in case of a detected accident an automatic test call at the apartment at first and alerts only when needed the additional support network.

The system was already established and tested in a laboratory environment by experimental designs with different scenarios on several subjects. The next step is followed by a practical test in which the system will be installed and tested in a real home environment which is currently in preparation.

7 Consortium of sens@home

In the following section, the project consortium of sens@home will be presented and their task in the project:

BruderhausDiakonie Reutlingen

- Project coordination,
- Involvement of users and development of requirements from the user perspective,
- Definition of potential accidents and emergency situations,
- Creation and maintenance of a real test environment.

Fraunhofer Institute for Manufacturing Engineering and Automation

- Assessment and selection of sensors,
- Concept and development of data fusion based on different sensors,
- Design and implementation of sensor-based scene analysis.

Vitracom AG

- Development and design of the sensor boxes
- Concept and implementation of sensor networks,
- Implementation of a system for visual recognition of persons
- Calculation of optical parameters for accident detection.

Sikom Software GmbH

- Design and implementation of communication and interaction between users and accident detection system,
- Calculation of acoustic parameters for incident detection,
- Development of a staged alarm system with the possibility of an automatic test call.

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Part II:
Assistance and Robotic Systems

Work Life in the Light of the Demographic Change: Case Study Force Assistive Device for Craftsmen

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Abstract. The trend of aging society has impacts on all parts of daily life. For instance work lifetime is expected to increase and in combination with rising quality and efficiency demands there is need for new technologies, working processes and assistance systems. For the latter, applied to the domain of craftsmen, systems seem to be reasonable which allow force assistance, augmentation, increase in safety and/or guidance functions. Required technology blocks to implement such functions are mainly available already today. This article is dealing with force assistance and describes an electro–mechanical system – the demonstrator of a so called "3rd Arm" – which actively supports the user when handling heavy power tools. The "3rd Arm" consists mainly of cost–effective mass–market compliant components. It is attached to a harness at the waist of the craftsman and relieves craftsmen from hard and fatiguing works. Two functions were implemented and evaluated. First the compensation of gravitational forces of the tool by means of a force control in order to achieve an utmost transparent behaviour. Secondly, so called "Virtual Fixtures" were used to implement a positioning assistance when repeating tasks are to be fulfilled at the same working height.

1 Motivation

In many areas of daily life (household, work and leisure time) a trend towards increased use of assistance functions and autonomous systems can be observed. "Aging society" is one of the key drivers whereas the increased availability of the necessary technologies serves as an enabler. In work life "aging society" is reflected in a constantly prolonging work life with at the same time increasing demands of quality and efficiency. However, with increasing age the physical fitness is declining. To compensate for this reduction of physical fitness, assistance systems can be used, such as so called "Wearable Robots". These are portable robot systems which can assist, improve or even replace the function of human extremities (see e.g. [1] for an overview). A distinction is made between therapeutical exoskeletons, robotic exoprostheses and extender–exoskeletons which multiply the muscular force. The latter can either run parallel to the user's extremities or can be formed as an end effector system which is only connected to the user at the end points (usually the hands). The system compensates respectively transfers forces which would otherwise act directly on the human body and introduces them at a less sensitive point at the torso or directs then to the ground. The use of robotic assistance systems in work environment can reduce the physical load, especially on the upper body. This prevents orthopedic long–term damage and enables a longer worklife while at the same time enhancing work efficiency and quality, even when performing heavy physical work. In production environment and in logistics applications actuated force– and lifting–assistance is already in use (e.g. available from Dalmec Ltd., UK or Scaglia INDEVA Spa, Italy). All known systems are stationary (not portable) and they require in part infrastructural changes. Other systems to support upper body regions can be found in the domain of rehabilitation, which are mostly stationary as well (for examples see [2,3,4,5]). Portable therapeutical systems are limited to specialized control functions, e.g. in the assistance to tremor patients [6]. Portable systems are also known from military and fundamental research, such as XOS (Raytheon/Sarcos Company, USA), BLEEX [7] (only for lower extremities) or HAL [8], which all address force assistance.

This paper introduces a system called "3rd Arm" which relieves craftsmen when working with heavy machine hand tools.

In order to evaluate how close such a system may be to commercialization in mass markets we considered as prerequisite the use of off–the–shelf low cost components.

For illustration purposes a typical use case is shown in Fig. 1. For mounting of insulation panels on the outside walls of buildings many drill holes have to be positioned in a regular pattern. The drilling machines used are rather heavy and the work is fatiguing. The use of floor–based support systems on construction sites is very restricted if not impossible (due to scaffolding). Therefore a portable, body mounted system is suggested.

The paper is structured as follows: Section 2 first describes the electromechanical system which was designed considering ergonomic aspects. Furthermore the sensor system, the electronic circuits and the safety system are described.

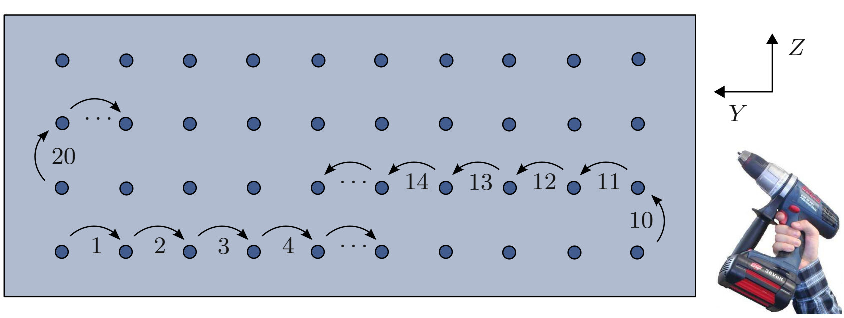


Fig. 1. Drill hole pattern for application of outside wall insulation

Section 3 describes the design of the controller structure, including the steps of modelling, system identification and application as well as the implemented control and assistance functions. Qualitative evaluation results of a small (not representative) study can be found in Sect. 4. The article closes with a summary and a short outlook.

2 Electromechanical System of "3rd Arm"

Unlike in classical exoskeleton systems the "3rd Arm" does not run in parallel to the users arm. Also it is not the users hand or forearm which is supported. Instead, it is the heavy working tool itself that is mounted on the actuated support structure of the "3rd Arm", which in return is then mounted on a harness worn by the user. Sensors on the control handle detect the users operating forces (user desire) which are then amplified by the actuators. The system is designed as an underactuated system for weight compensation and height positioning assistance.

2.1 Mechanical Setup

To ensure an invariable parallel orientation of the working tool the main system structure is carried out as a parallelogram structure (Fig. 2). The system's actuation is implemented by diagonally arranged linear drives. Tension springs are used to minimize the energy required to hold the static system (gravity compensation). This way the drives only need to deflect the system from a balanced middle position (Fig. 3). The linear actuators consist of low–cost brushed DC motors with 5 : 1 planetary gears which drive ball screw spindles.

As shown in Fig. 4 the system itself is mounted on a harness on the user's back and waist.

One requirement for the layout of the kinematic structure was that force–assisted working is possible within the entire human work space (Fig. 5). It shall be ensured that the system is usable within this workspace without any deadlocks (= singularities).

2.2 Electronic System

Designing the system as a "wearable robot" provokes the following constraints:

- highest possible safety requirements due to high degree of interaction between man and machine
- high energy efficiency (energy storage has to be carried by user): low dissipation loss, high degree of efficiency for all components
- robustness due to targeted application area (craftsmen, construction sites)

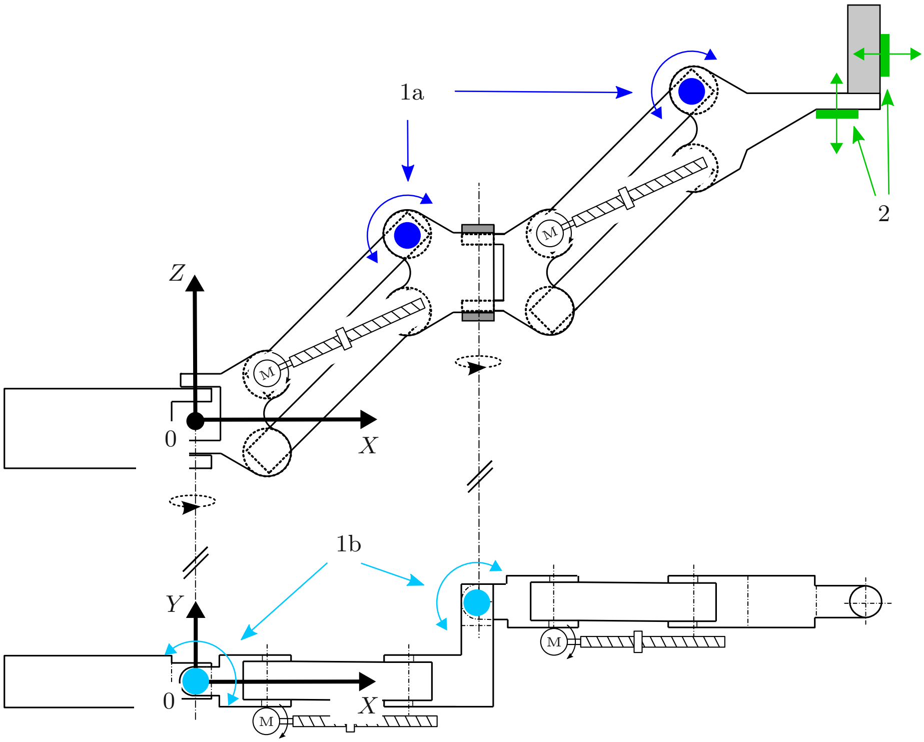


Fig. 2. Mechanical setup as parallelogram structure with $f = 4$ Degrees of Freedom (DoF): two active DoF in z–direction and two passive DoF rotating around z–axis. (1) angle sensors, (2) force sensors.

Microcontroller. Two microcontrollers are used to control the system:

– μC1 (ARM9 Core, 32–bit, 266 MHz), which represents the outer control loop of the cascaded control (force control) and which is also responsible for data processing of the higher software layers
– μC2 (MPC560xP, 32–bit, 64 MHz) for interfacing sensors and actuators also implements the inner control loops (e.g. motor current control) and implements as well the relevant monitoring functions (e.g. overcurrent protection, battery charge state)

Safety Circuits. Both microcontrollers continuously generate a pulse width modulation signal (alive–signal) which is monitored by a discrete safety circuit. As soon as the signal parameters show signs of irregularity the system is switched in hardware to a fail–safe mode. The maximum allowed angles of the joints are monitored by software as well as by hardware limit switches which are directly wired to relays and switch off the drives immediately in case of contact.

Fig. 3. Linear actuator with tension springs

Fig. 4. Assistive support system "3rd Arm"

Sensor System. For the implementation of the basic functions the joint positions of the active joints as well as the user desire have to be detected. The joint positions can either be measured directly at the joint pivot point or derived indirectly by the position of the drive spindle of the actuator. To minimize interference of elasticities of the mechanical system a joint position measurement directly at the joint pivot point was considered. This is done contactless by a magnetic angle encoder with 10– or 12–bit resolution. The user request detection is done by force measurement on the handle. To ensure a high transparency of the system even smallest changes in hand forces applied by the user have to be detected. The system as described here uses strain gauges which like the magnetic angle decoders are free of wear.

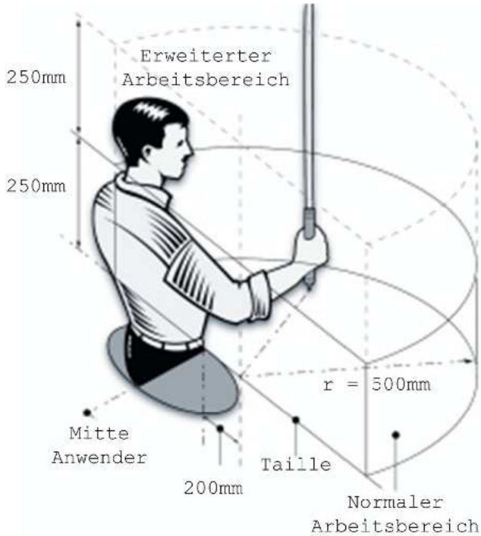


Fig. 5. The human workspace [9]

3 Control

The following steps were carried out for control design:

- modelling and simulation
- system parameter identification
- selection of suitable control structures
- implementation of additional functions

The following subsections describe these steps in detail.

3.1 Modelling

Modelling was done by means of a multibody system. The system was cut free at the user anchor point which eliminates the user's body movements (Fig. 6). As a result the vector of generalized variables is of 4^{th} degree

$$\boldsymbol{q}(t) = \left[\ \underbrace{q_1(t)\ q_2(t)\ q_3(t)\ q_4(t)}_{\text{Robot}}\ \underbrace{\cancel{X_0\ Y_0\ Z_0\ \theta_1\ \theta_2\ \theta_3}}_{\text{User}}\ \right] \tag{1}$$

with the particular variables described in Fig. 6.

Figure 7 depicts the respective mechanical components like masses and lengths. The masses are assumed as concentrated. From this model the forward kinematics for the end effector position $\boldsymbol{P}_{\text{Effector}}(t)$ can be determined

$$\boldsymbol{P}_{\text{Effector}}(t) = \boldsymbol{\varphi}\big(\boldsymbol{q}(t)\big), \quad \boldsymbol{\varphi}(\cdot) : \mathbb{R}^4 \to \mathbb{R}^3 \tag{2}$$

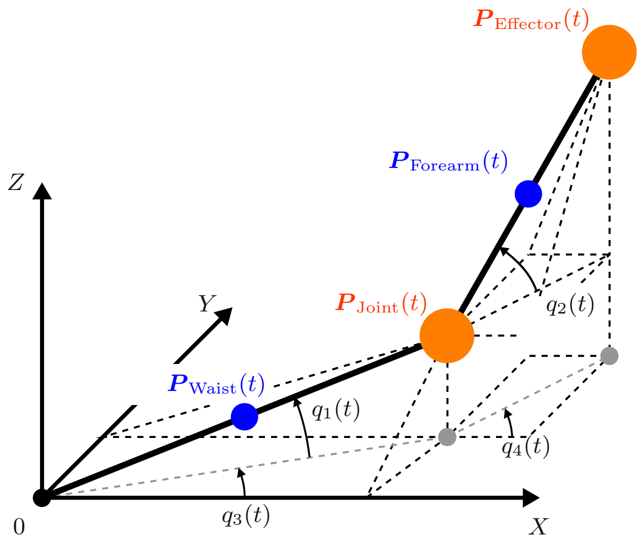


Fig. 6. Simplified system neglecting user's body movement

The partial derivative with respect to the generalized coordinates $\boldsymbol{q}(t)$ delivers the Jacobi–Matrix $\boldsymbol{J}(\boldsymbol{q})$

$$\boldsymbol{J}(\boldsymbol{q}) = \frac{\partial \boldsymbol{\varphi}\big(\boldsymbol{q}(t)\big)}{\partial \boldsymbol{q}(t)} \tag{3}$$

Using the kinetic and potential energy of the overall system ($T(t)$ and $U(t)$) the Lagrange function $L(t)$ can be set up. Using the Lagrange equations

$$\frac{d}{dt}\left(\frac{\partial L(t)}{\partial \dot{\boldsymbol{q}}(t)}\right) - \frac{\partial L(t)}{\partial \boldsymbol{q}(t)} = \boldsymbol{\tau}_{\text{Ext}}(t), \quad L(t) = T(t) - U(t) \tag{4}$$

the descriptive differential equations of motion can be derived as follows.

$$\boldsymbol{M}\big(\boldsymbol{q}(t)\big)\, \ddot{\boldsymbol{q}}(t) + \boldsymbol{C}\big(\boldsymbol{q}(t), \dot{\boldsymbol{q}}(t)\big) + \boldsymbol{F}\big(\boldsymbol{q}(t), \dot{\boldsymbol{q}}(t)\big) + \boldsymbol{G}\big(\boldsymbol{q}(t)\big) + \boldsymbol{\tau}_{\text{Elas}}(t) = \boldsymbol{\tau}_{\text{Ext}}(t) \tag{5}$$

In known notation $\boldsymbol{M}\big(\boldsymbol{q}(t)\big)$ represents the mass matrix which describes inertial effects, the vector $\boldsymbol{C}\big(\boldsymbol{q}(t), \dot{\boldsymbol{q}}(t)\big)$ describes the Coriolis– and centrifugal terms, $\boldsymbol{F}\big(\boldsymbol{q}(t), \dot{\boldsymbol{q}}(t)\big)$ is the vector of the friction effects, $\boldsymbol{G}\big(\boldsymbol{q}(t)\big)$ is the vector of the gravitational terms, $\boldsymbol{\tau}_{\text{Elas}}(t)$ represents the elastic terms and $\boldsymbol{\tau}_{\text{Ext}}(t)$ represents the vector of the generalized external forces and torques.

Using the Jacobi–Matrix $\boldsymbol{J}(\boldsymbol{q})$ the projected workspace was analyzed for singularities. By choosing suitable parameters for the mechanical system (limb lengths and permissible joint angles) it is ensured that no singularities (= deadlocks) can occur within the chosen workspace. Figure 8 visualizes the geometrical location of singularities, which are all located outside the reachable workspace.

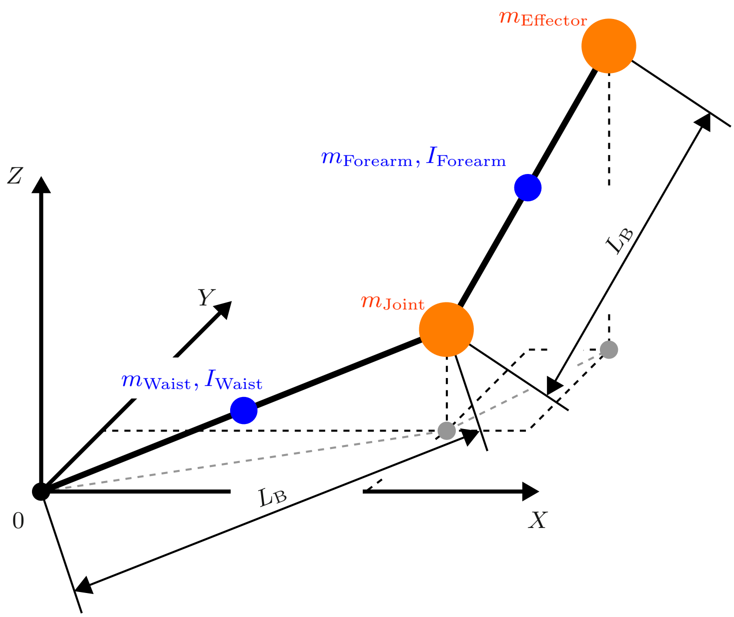


Fig. 7. Kinematic structure of the simplified model with masses and lengths

3.2 Parameter Identification

For identification of the unknown system parameters only the active joints were considered, i.e. the passive pivoting motions in the horizontal plane (along z–axis) were neglected. By use of suitable excitation, gravitational parameters, actuator inertia and dry and viscous friction parameters were successively determined. For doing so the equations of motion were reformulated in a way that they could be described using a linear parameter vector $\boldsymbol{\Lambda}$ of minimal order and a system matrix $\boldsymbol{W}$ that describes all nonlinear terms of the model (base parameter method):

$$\boldsymbol{\tau}_{\mathrm{Ext}}(t)-\boldsymbol{\tau}_{\mathrm{Elas}}(t) = \boldsymbol{M}\big(\boldsymbol{q}(t)\big)\ddot{\boldsymbol{q}}(t)+\boldsymbol{C}\big(\boldsymbol{q}(t),\dot{\boldsymbol{q}}(t)\big)+\boldsymbol{F}\big(\boldsymbol{q}(t),\dot{\boldsymbol{q}}(t)\big)+\boldsymbol{G}\big(\boldsymbol{q}(t)\big) \quad (6)$$

$$\Delta\boldsymbol{\tau}(t) = \boldsymbol{W}\big(\boldsymbol{q}(t),\dot{\boldsymbol{q}}(t),\ddot{\boldsymbol{q}}(t)\big)\ \boldsymbol{\Lambda} \quad (7)$$

This was followed by a two–stage identification, for which a partitioning of the linear parameter vector $\boldsymbol{\Lambda}$ in two vectors $\boldsymbol{\lambda}_{\mathrm{G}}$, $\boldsymbol{\lambda}_{\mathrm{I}}$ and the system matrix $\boldsymbol{W}(\cdot)$ in three matrixes $\boldsymbol{W}_1(\cdot)$, $\boldsymbol{W}_2(\cdot)$, $\boldsymbol{W}_3(\cdot)$ was carried out:

$$\Delta\boldsymbol{\tau}(t) = \boldsymbol{W}_1\big(\boldsymbol{q}(t),\dot{\boldsymbol{q}}(t)\big)\ \boldsymbol{\lambda}_{\mathrm{G}} + \boldsymbol{W}_2\big(\boldsymbol{q}(t),\ddot{\boldsymbol{q}}(t)\big)\ \boldsymbol{\lambda}_{\mathrm{G}} + \boldsymbol{W}_3\big(\dot{\boldsymbol{q}}(t),\ddot{\boldsymbol{q}}(t)\big)\ \boldsymbol{\lambda}_{\mathrm{I}} \quad (8)$$

Finally a parameter estimation using the Least–Squares method was done. For determining the gravitational parameters the system was excitated with

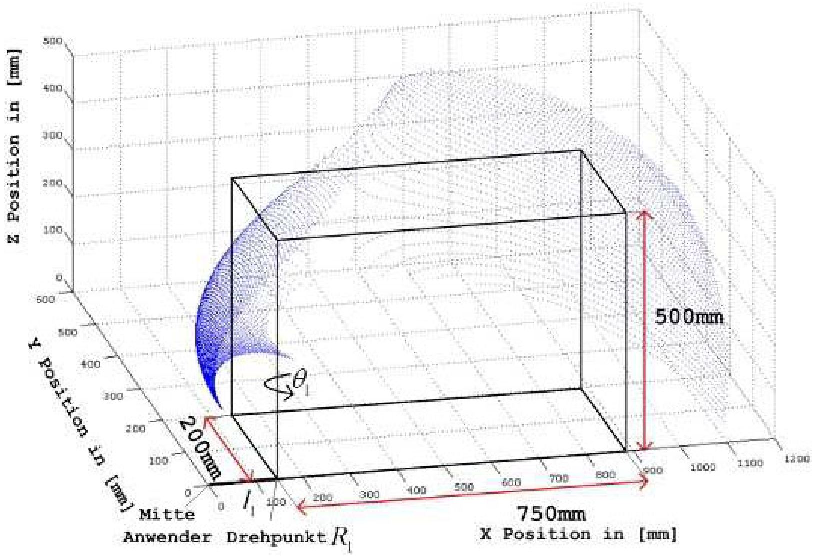


Fig. 8. Point cloud with singularities of the end effector (blue dots). Compared with chosen workspace (box), which is free of singularities.

trapezoidal trajectories with a low angular velocity (quasi–stationary). By doing so all system elements associated with acceleration are eliminated

$$\Delta\boldsymbol{\tau}(t) = \boldsymbol{W}_1(\cdot)\ \boldsymbol{\lambda}_\mathrm{G} \tag{9}$$

From that the gravitational and dry friction parameters can be determined as

$$\boldsymbol{\lambda}_\mathrm{G} = \left(\boldsymbol{W}_1(\cdot)^\mathrm{T}\ \boldsymbol{W}_1(\cdot)\right)^{-1}\boldsymbol{W}_1(\cdot)^\mathrm{T}\ \Delta\boldsymbol{\tau}(t) \tag{10}$$

In a second step an excitation with a higher share of acceleration was applied. Making use of the already estimated parameters leads to

$$\underbrace{\Delta\boldsymbol{\tau}(t) - \boldsymbol{W}_1(\cdot)\ \boldsymbol{\lambda}_\mathrm{G} - \boldsymbol{W}_2(\cdot)\ \boldsymbol{\lambda}_\mathrm{G}}_{\Delta\boldsymbol{\tau}'(t)} = \boldsymbol{W}_3(\cdot)\ \boldsymbol{\lambda}_\mathrm{I} \tag{11}$$

The rest of the parameters (inertial and viscous friction parameters) are then calculated as follows:

$$\boldsymbol{\lambda}_\mathrm{I} = \left(\boldsymbol{W}_3(\cdot)^\mathrm{T}\ \boldsymbol{W}_3(\cdot)\right)^{-1}\boldsymbol{W}_3(\cdot)^\mathrm{T}\ \Delta\boldsymbol{\tau}'(t) \tag{12}$$

A comparison between measurements done on the actual system and a simulation using the estimated parameters shows a good correlation (see Fig. 9).

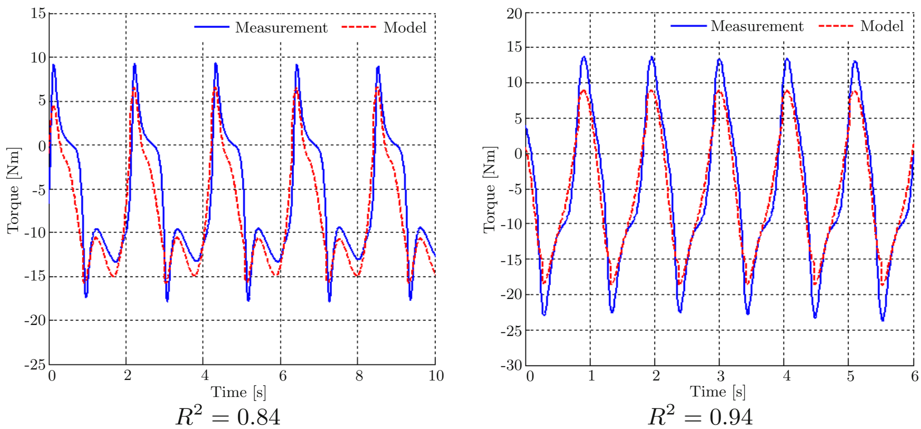


Fig. 9. Comparison of measurement data and simulation result regarding torque for identical movements. The coefficient of determination R^2 indicates a good correlation.

3.3 Control Strategy

A vital prerequisite for the acceptance is a suitable design of the man machine interface. For that reason the control design is of high importance, e.g. in order to obtain a high degree of system transparency. Several control principles are known and are the subject of intensive research. Haptic interfaces are typically based on impedance or admittance control [10]. Such approaches allow for compensation of the manipulator's weight and to some extend also of its inertia. "Generalized Elasticities" [11] can be used to mask remaining inertias from the user. To assist the user in performing special tasks such as telepresence operations "Virtual Fixtures" [12] are used, which limit the user's movements to certain areas or directions. When using the hierarchical concept of "Shared Control" [13,14,15], the user's task is mainly motion planning, while the fine manipulation is done by subordinate control loops. Robotic support can also be realized elastic, e.g. using potential fields which indicate correct movements without enforcing them. For actuated prosthestic legs or exoskeletons the method of "Complementary Limb Motion Estimation" [16,17] is known, which uses the motion pattern of the rest of the body to estimate the desired motion of the supported limb. A pure force assistance system such as BLEEX [18] can increase physical performance. Prerequisite for the use of the control principles "Generalized Elasticities" und "Shared Control" is that the movement patterns are known in advance. The use of "Complementary Limb Motion Estimation" is only practical if the movement of the limbs can be measured. Therefore, for an assistive system for craftsmen which should allow most flexible operation especially the principle of impedance control for gravity compensation in combination with "Virtual Fixtures" for providing potential fields seems to be promising.

Zero–Force Control. The following is valid for the zero–force control in this system:

- passive actuation of the assistance system by external forces
- forces acting on the end effector have to be compensated by torques applied to the joints

The principle of "virtual work" is used to derive the interrelation of external forces and actuator torques. The interrelation results from the already introduced Jacobi–Matrix:

$$\boldsymbol{\tau}(t) = \boldsymbol{J}(\boldsymbol{q})^{\mathrm{T}}\ \boldsymbol{F}(t) \tag{13}$$

$$\begin{bmatrix} \tau_1(t) \\ \tau_2(t) \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} -L_{\mathrm{B}}\ s_1\ c_3 & -L_{\mathrm{B}}\ s_1\ s_3 & L_{\mathrm{B}}\ c_1 \\ -L_{\mathrm{B}}\ s_2\ c_{3+4} & -L_{\mathrm{B}}\ s_2\ s_{3+4} & L_{\mathrm{B}}\ c_2 \\ -L_{\mathrm{B}}\,(c_1 s_3 + c_2 s_{3+4}) & -L_{\mathrm{B}}\,(c_1 c_3 + c_2 c_{3+4}) & 0 \\ L_{\mathrm{B}}\ c_2\ s_{3+4} & L_{\mathrm{B}}\ c_2\ c_{3+4} & 0 \end{bmatrix} \begin{bmatrix} F_{\mathrm{x}}(t) \\ F_{\mathrm{y}}(t) \\ F_{\mathrm{z}}(t) \end{bmatrix} \tag{14}$$

whereas s_1 is a short notation for $\sin\big(q_1(t)\big)$ and s_{3+4} for $\sin\big(q_3(t) + q_4(t)\big)$ (respectively c_1 and so on).

An actuation is only possible in z–direction, in x– and y–direction the system is passive. Hence the following applies:

$$F_{\mathrm{x}}(t) = F_{\mathrm{y}}(t) = 0 \tag{15}$$

The distribution of the z–force on both actuators is determined as

$$\begin{bmatrix} \tau_1(t) \\ \tau_2(t) \end{bmatrix} = \begin{bmatrix} L_{\mathrm{B}}\ c_1 \\ L_{\mathrm{B}}\ c_2 \end{bmatrix} F_{\mathrm{z}}(t) \tag{16}$$

Impedance Control in Cartesian Space. Figure 10 shows the implemented controller structure which consists of four elements. The inner loop implements a force control loop (1). Feed–forward elements compensate gravitational terms of the tool weight and the weight of the "3^{rd} Arm" itself (2). A safety function ensures that the system stiffens in the proximity of the end stops, i.e. the actuators produce an increasing counterforce as the end stops are approached (3). Finally, the guidance function is implemented in an outer control loop by generating force setpoints (4). That way the system can e.g. be stiffened at predefined height levels ("Virtual Fixtures").

Additional Functions. In addition to the gravity compensation of the working tool, additional assistive functions may offer benefit for the user.

Additional Function Positioning Aid. The use case shown in Fig. 1 requires for many drill holes set at identical height levels. The user is supported by a virtual "lock" of the working tool at a height. When the user approaches with the tool the height of the target plane, the tool is "attracted" in z–direction, i.e. it slips on a virtual potential plane to its target height. To leave this potential plane in z–direction up– or downwards, a force has to be applied. The movement between the potential planes is then effortless again, i.e. the zero–force control is applied (see Fig. 11, 12).

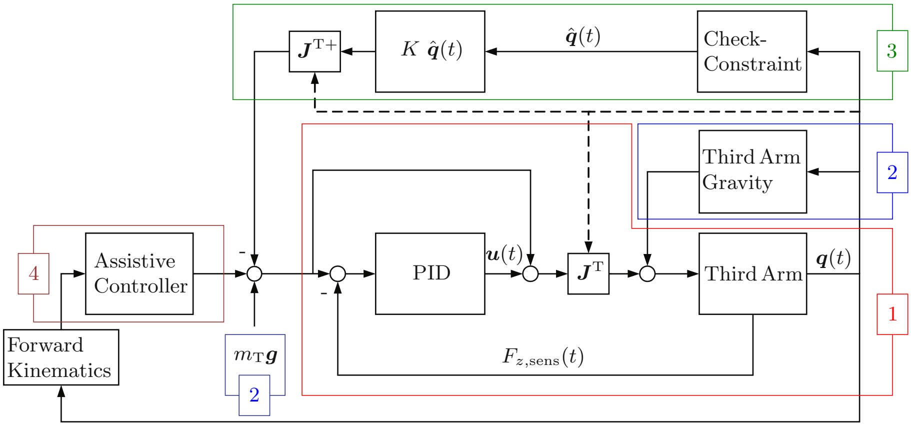


Fig. 10. Complete controller structure including force control loop (1), feed–forward of gravitational terms (2), system stiffening in proximity to end stops (3), potential field based assistance function (4)

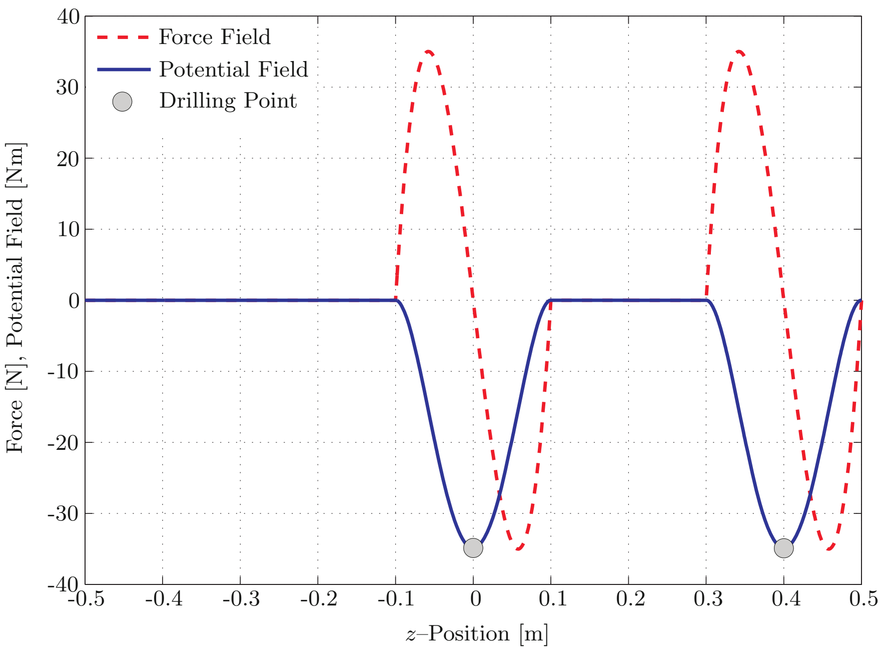
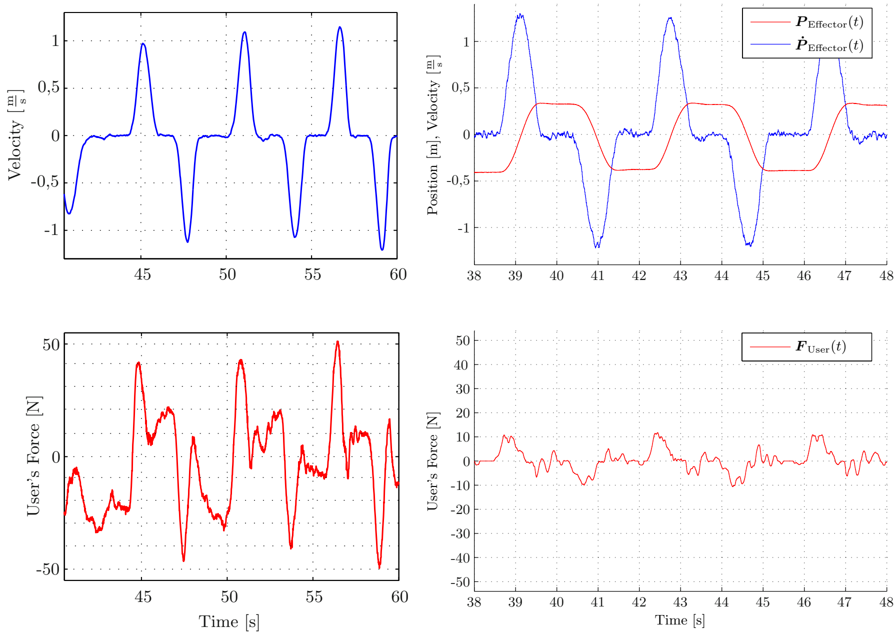


Fig. 11. Positioning aid using a potential function: In this example z–position locks are set at $z = 0\,\mathrm{m}$ and $z = 0.4\,\mathrm{m}$



(a) without control (b) with control

Fig. 12. User's force required without (a) and with force assistance system (b) at comparable speed profiles

Compensation of User's Body Movements. Up to now the user's body movements have been neglected in the control structure. Yet these are omnipresent (due to walking, breathing, uneven ground, etc.) and influence the absolute positioning of the end effector in the workspace. As long as these movements are known they can be compensated and balanced out. For detecting the user's body movements e.g. laser scanners can be used which determine the systems position in space. A cost–effective approach is the use of laser range finders e.g. on the end effector which measure the three spatial directions. As long as the system is only actuated in z–direction (as described here) the use of one laser range finder in z–direction is sufficient. This system extension still needs to be implemented.

4 Evaluation

4.1 System Evaluation

The comparison of a passive to our active support system shows a significant reduction of the users actuation force (Fig. 12).

Also the implemented z–positioning assistance using potential planes showed good results (Fig. 13).

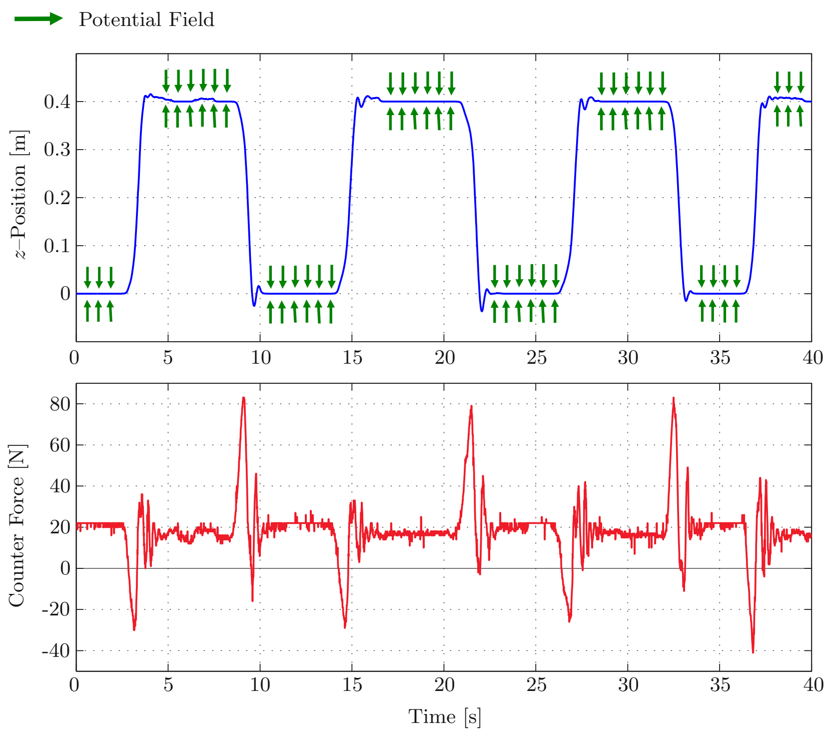


Fig. 13. z–positioning assistance using potential functions: Counter forces applied by system to ensure attraction to desired height plane.

4.2 Derived Success Factors

The force applied by the user is a measurable parameter to indicate the functional quality. Yet for the evaluation of haptic man–machine–interactions it is advisable to take into account subjective criteria (feel and touch) as well in addition to the purely objective criteria. For doing so a small user survey was conducted (ten test persons). Evaluated was the overall functionality, the necessary user force (transparency), manoeuvrability and different z–position potential functions. The overall functionality was rated positive. The necessary force was reduced by over 75 %.

The acceptance tests also showed the following success factors:

- high degree of transparency necessary (to compensate for the elasticities of the mechanical system)
- low system weight, especially of the "3rd Arm" itself
- low power consumption (as far as possible assisted by springs)
- sufficient robustness for projected work environment "craftsmen/construction site"

5 Summary and Outlook

A first demonstrator of a "3rd Arm" support device has been set up, which offers assistance when working with heavy machine tools. Two functions are implemented and tested: Force assistance for gravity compensation and a positioning aid function for repetitive working tasks in defined working heights. In a short survey success factors were derived which will be considered in the development of the next version. On the one hand this is a weight reduction (due to a transfer of the actuators from the "3rd Arm" to the harness), on the other hand an increase of the systems transparency due to a control system with higher bandwidth. In addition to that the system will be extended by a localization system to enable additional functions.

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Criteria for Quality and Safety while Performing Unobtrusive Domestic Mobility Assessments Using Mobile Service Robots

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Abstract. A new concept for safely performing and qualitatively evaluating assessments in domestic unsupervised environments, especially when utilizing mobile service robots, is presented. The presented approach is based on the idea that classical geriatric assessments, especially from the domain of mobility, may be divided in components which happen naturally throughout the day in domestic environments. Those components are measured separately and are recombined to com-plete assessment tests later on. In order for physicians to decide how reliable assessment results from the domestic do-main are, we define technical quality criteria for the components of the Timed Up&Go assessment test. The approach is evaluated within an experiment in a living lab utilizing sensors, especially a laser range scanner, equipped with a mobile robot. Results show that the presented approach may be used to separate sensor measurements promising good assess-ment results from those containing insufficient data. Additionally, using mobile robots to perform assessments in domestic environments holds the potential danger for the inhabitant to stumble over the robot. Therefore, the paper also evaluates the aspect of inhabitants' safety during domestic assessments based on the experiment's data. A novel approach to navigate safely using the previously presented approach of optimal observation lots (OOL) is presented.

Keywords: mobility assessment, quality, safety, mobile service robot, domestic environments, ambient assisted living.

1 Introduction

A key to overcome the problems imposed by the demographic change could be the use of assistive technologies [1]. Such technologies can help care givers and support elderly in their daily tasks. An interesting field is medical assessments, especially transferring mobility assessments to domestic environments. These could help to recognize early signs of age-related diseases or enable physicians to advise patients back home after rehabilitation, thereby reducing costs and manpower demands.

Most approaches for performing mobility assessments at home require either modification at the home infrastructure (e.g. mounting sensors on walls or floors) or active integration of the subjects (wearing sensors attached to the body). We propose to use an assistive robotic system to perform the mobility assessment measurements. This decreases the need of external infrastructure but enables to integrate smoothly into existing infrastructures (smart homes).

However, in order for physicians to infer medical decisions from assessment results recorded in unsupervised environments and situations like personal homes of patients, criteria for assuming the reliability of results have to be available. Flexibility of sensor information and assessment setup comes with the price of less reliability from a clinical perspective. Additionally, safety of inhabitants is an important issue since better assessment results may not be gained despite higher risk for inhabitants. Within this paper a novel approach to performing qualitative and safe mobility assessments in domestic environments using mobile robots is motivated, presented, and evaluated.

2 Medical Motivation

A person's mobility, i.e. being able to move around and to get into and to keep up certain body positions, is closely connected to his or her perceived quality of life and a fundamental requirement for an independent lifestyle. Due to age-related changes and the increasing number of pathological reasons especially elderly people are in danger of an impaired mobility and thus suffer from reducted self-care ability and increaed risk of falling [2]. The branch of medicine which deals predominantly with elderly and multi-morbid patients is called geriatrics. The ultimate aim of each geriatric treatment is to recover and maintain an independent lifestyle of the patients. Making an exact diagnosis becomes less important and is often not even possible due to multi-morbidity of patients. Instead, functional status of patients is estimated and possible deficits are removed by means of rehabilitation or provision of aid. The estimation of a geriatric patient's functional status happens within the geriatric assessment which is a "multidimensional process designed to assess an elderly person's functional ability, physical health, cognitive and mental health, and socio-environmental situation" [3]. In order to assess a person's functional ability in a certain domain various so called assessment tests have been developed. Mobility is one of the most important aspects of a geriatric assessment. The probably most often applied assessment test in the field of mobility is the so called Timed Up&Go (TUG) test [4]. Although providing a good insight into peoples' abilities in rather short time, there are several drawbacks about geriatric assessments in today's health care systems e.g. place of execution, test awareness of patients, subjective execution by caregivers, and required effort for executing and documenting assessment tests [5]. In today's health systems mobility assessments are only applied infrequently or after an acute incident like a fall took place. Potential for prevention of incidents, early diagnosis, or monitoring of rehabilitation progress is not exploited. Bringing assessments to domestic environments by use of sensor technologies could provide new insights for physicians, enable more effective health care by provisioning of early, more reliable, and more frequent assessment results, increase quality of life for people concerned, and may save costs for the health care system.

3 State of the Art

Assessments in domestic environments can only be implemented economically reasonable by use of sensor technologies. Initially, two main approaches arose using either wearable sensors or sensors installed into the environment, so called health smart homes [6]. Recently, usage of service robots for bringing assessments to peoples' homes has been investigated. Since our ultimate aim is to implement unobtrusive assessment technologies which do not require explicit interaction of the user with any device, the focus within this section is on ambient sensor technologies for implementing assessments only.

3.1 Mobility Assessments in Smart Environments

Environments equipped with various sensors especially from the home automation or security domain, are referred to as (health) smart homes [6]. Very few systems for detailed mobility analysis based on ambient sensors have been described so far. Instead, most research focused on general mobility trend analysis.

Home automation technologies like motion sensors, light barriers, or reed contacts placed in door frames or on the ceiling have been used by various research groups. An approach presented by Cameron et al. [7] employ optical and ultrasonic sensors placed in door frames to determine the walking speed and direction of a person passing. Pavel et al. [8] developed a system based on passive motion sensors covering various rooms of a flat. Gait velocity could be computed by dividing known distances between coverages by measured transition times. Placing three passive motion sensors in a sufficient long corridor makes those computations more reliable [9]. Within our own work [10] we have recently presented a new approach based on the definition of motion patterns by usage of available sensor events. By providing an abstracted definition of the environment, physically possible walking paths can be computed and monitored automatically.

Recently, more precise sensors from the domain of robotics i.e. laser ranges scanners have been applied to implement very precise gait analysis in domestic environments. An approach presented by Pallej et al. [11] provides a very detailed analysis, but they require people to walk straightly towards the scanner on a predefined path. Within our own work using laser range scanners [12] we do not restrict a person's walking path while measuring but have so far only presented the computation of self-selected gait velocity. The approach is highly precise and does not require any predefined knowledge but is, compared to our approach using home automation technology, more expensive to implement.

3.2 Mobility Assessments Using Service Robotics

Service robots combine results of different fields of robotic research into systems that are specifically targeted at an application. Most available platforms are still in (advanced) research states. Acting autonomously in home environments [13] and learning of environmental factors and user behavior [14] are intensively developed at the moment, as well as robot design itself [15]. Within our own work [16] we have recently presented a new approach to enhance mobile robot navigation in domestic environments by the use of mobility assessment data. An application of the potential field method to mobility trend analysis and the precise measurements of human movement trajectories by a laser range scanner have been employed. These were used to provide a possibility for large-scale and long-term mobility assessment in home environments. A combination of common path planning algorithms known from the field of robotics and a precise way to measure movement trajectories of the human via a laser scanner at home was presented. A mobile robot will thereby act as a kind of mobile infrastructure bringing the needed sensor technology to the optimal place for monitoring, as introduced in [17]. To perform services and assessments without compromising the safety of the owner, the robot will start with an observation phase. During this phase the robot stands at a safe place in the initial room of the home environment and observes the human behavior and environment. Collected data is used to compute the safety criteria (section 6).

3.3 Limitation of the State of the Art

Regarding available sensor technologies, usage of highly precise ambient sensors equipped with mobile service robots in combination with sensors available in the environment seems to promise the best assessment results. Given the fact, that those devices will certainly not come in households for the purpose of performing assessments but for provision of service and support may render their currently rather high costs reasonable. Additionally, expensive sensors will only have to be equipped once with the robot and are available in the whole environment due to the robot's mobility. The greatest problem about usage of ambient sensors is the fact that available sensor data often makes it difficult to assign assessments results to certain persons when applying such sensor in a multi-person household. Although there are various approaches available to bringing mobility assessments to domestic environments, comparison of domestic and clinical assessments results remains problematic and thus clinical decisions to infer from domestic assessment results are still unclear. The reason is that assessments at home do not happened in a standardized environment and many disturbing factors are present. In terms of WHO's International Classification of Functioning and Disabilities (ICF) [18] this means that clinical assessment results represent the capacity of a patient in a certain domain (optimal results free of any disturbance) while domestic assessments measure performance (what an individual does in his or her current environment regarding all natural environmental influences). While information value of clinical assessment results is clear from many

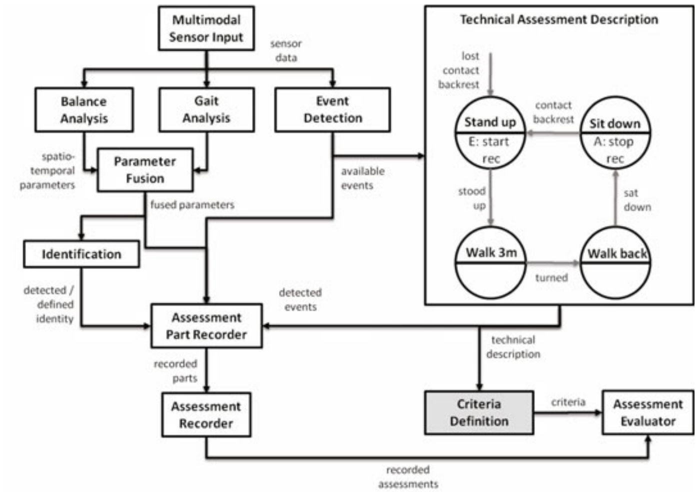

Fig. 1. Approach to Performing Domestic Assessments

trials, do domestic assessments results reflect much more from what is actually relevant to self-care ability. The relationship of clinical and domestic assessment results has also been described with the three-dimensional-layer-model (3DLC) [19]. What is actually missing to make results comparable is a set of quality criteria. This will enable physicians to decide on the level of trustworthiness he or she assigns to domestic assessment results and to infer qualified clinical decisions from this data.

4 Approach

We present a novel approach (Figure 1) to perform assessments in domestic environments and to validate those assessments qualitatively according to defined criteria. The approach is based on the idea that assessments in the domestic domain are not explicitly executed as tests with a prescribed sequence supervised by a physician like in professional environments but that assessments are recorded in parts throughout the day and that those parts are recombined to complete assessments later on. While an approach is required to recombine the single parts, within this paper we focus on the definition of quality criteria which allow estimating how reliable parts and thus the whole assessments have been performed. Our approach is designed for mobility assessments but may in general be applied to assessment tests in other domains as well. Another important aspect of domestic assessments is to ensure the inhabitant's safety especially if assessments are performed by a mobile robot which may be an obstacle. Therefore, the aspect of safety during assessments is discussed based on the results of the conducted experiment for validating our approach to quality estimation of domestic assessment.

Most assessment tests can be divided into distinct, basic actions which are performed by most people several times throughout the day like e.g. walking a certain distance or standing up from a chair. Within our approach (Figure 1) such basic actions are described as finite state machines called the "technical assessment description". Events required for change of states are retrieved from collected data from available multimodal sensors. In order to perform mobility assessments, retrieved sensor information is additionally used to perform gait and balance analysis. Computed parameters are then fused and used for performing identification of the user (a static user ID may be provided as well) and in general for assessment recording. Research has shown that several parameters of gait and balance are sufficient for performing identification as far as there are not too many subjects [20]. As soon as a state change indicates that a certain part of an assessment has started, the assessment part recorder starts to record the corresponding part of the assessment using available parameters. Recorded assessment parts are labeled with the detected ID and are forwarded to the assessment recorder which recombines parts to assessment tests according to the technical description. Completed assessment test recordings are forwarded to the assessment evaluator whose task is to evaluate the single parts and the whole assessment according to the defined quality criteria.

This paper is focused on the definition and evaluation of those quality criteria for the most frequently used mobility assessment in the geriatric domain: Timed Up&Go (TUG) [4]. Within the next sections the component-based TUG assessment test and related quality criteria are described and evaluated within an experiment conducted in a living lab with a mobile service robot.

4.1 Components and Events of TUG

The TUG has been introduced by D. Podsiadlo and S. Richardson in 1991 [4] as a simplified clinical test for evaluating, especially elderly, patients' general mobility and balance. Within TUG a stopwatch is used to measure the time a patient takes to complete a set of components: rise from a chair, walk 3m, turn around, walk back, and sit down again. According to the time taken by the patient to complete the test, he or she is arranged into a result group which gives a hint to the treating caregiver for required actions. An extension of the classical TUG, called Expanded Timed Get-up-and-Go (ETGUG) [21], is meant to provide an even better insight in patient's mobility.

Within our own research [22] we have recently described how to recognize and measure the duration of TUG components using a set of ambient multimodal sensors attached to a chair. The defined components are: Standing up (1), walking there (2), turning (3), walking back (4), and sitting down (5). Components are defined by start-events and end-events. Events available within our approach are "seat off" (lost contact to the back of the chair), "gait initiation" (started to walk away), "turn initiation" (started to turn around), "turn termination" (fully turned towards the chair), "gait termination" (standing in front of the chair again), and "seat on" (made contact to back of the chair again). Those events are detected objectively by processing the available sensor data. The time between the occurrence of those events corresponds to the duration of the components of TUG e.g. the duration of "walking there" is computed by subtracting the time the event "turn initiation" occurred by the time "gait initiation" happened. For more information on components and on how events are detected within our approach, please refer to [22].

4.2 Quality Criteria for TUG

Our approach to domestic assessments is based on the idea to measure the single components of TUG throughout the day and to recombine these single measurements to a complete TUG assessment test later on. However, in domestic environments the TUG components will in most situations not happen in a predefined flow like in professional environment and not all measurements will be sufficient enough to represent a component of TUG. Therefore, we define quality criteria whose aim is to decide whether a recorded measurement can be used as a component of the TUG assessment test. It is important to see that these criteria are no assessment results but do just define if a measurement can be used for retrieving assessment results for a certain assessment component. Which component may be contained in recorded measurements and thus which criteria are applied is detected by generated events according to our approach described in [22]. The criteria definitions are independent on any special sensors. However, within our experiment we describe how we mapped some criteria to measurements of a mobile robot's sensors.

The maximum validity score vscomponent a measurement can reach is 1. All criteria for a component are considered to evenly influence the validity. Therefore, all single criteria score functions $f_{component}^{criterium}(x)$ are defined as binary functions and are normalized to 1. Some score functions do additionally tell how good a measurement can fulfill the corresponding criteria others can only tell whether it is fulfilled or not. All criteria scores of a component's quality function are summed up and divided by the number of criteria $\#criteria$ of a component to find the overall validity score. The general validity formula 1 is:

$$VS_{compoent} = \frac{\sum_{c=1}^{\#criteria_{component}} f_{component}^{criterion}(x)}{\#criteria_{component}} \tag{1}$$

We divide the TUG assessment test into five components: Standing up, walking there, turning, walking back, and sitting down. Quality criteria for walking there and walking back are very similar and are therefore presented in a combined section.

Quality Criteria for Standing Up. The first component of TUG is standing up. Standing up starts as soon as the inhabitant looses contact with the backrest of the chair (the clinical version starts with the command of the physician to start) and ends with the first step away from the chair. This means that all sensor measurements between an event for loosing contact to the backrest of a chair and an event for movement away from the chair can represent the component standing up.

In order for those measurements to be a valid representation of the component, the inhabitant has to complete the process of standing up and a fallback into the chair should not happen in between (2). Additionally, standing up should be a continuous movement. The inhabitant should not just sit leaning forward and then stand up minutes later. This means that the time between lost of contact to the backrest and loss of contact to the chair $t_{standing}$ should not exceed a certain threshold $t_{max}^{standing}$ (3). Therefore, the component standing up has two quality criteria defined in formulas 2 and 3:

$$f_{standing\ up}^{complete}(x) = \begin{cases} 1 & nofallback \\ 0 & otherwise \end{cases} \tag{2}$$

$$f_{standing\ up}^{continuous}(x) = \begin{cases} 1 & t_{standing} < t_{max}^{standing} \\ \frac{t_{max}^{standing}}{t_{standing}} & otherwise \end{cases} \tag{3}$$

Quality Criteria for Walking There and Walking Back. Walking there and walking back are the movement away and back towards the chair again. Walking there starts with the first movement away from a chair and ends as soon as turning starts. Walking back starts as soon as the turning is finished and first movement towards the chair is detected and ends when the movement stops again. However, in domestic environments all movements independent from movement towards or away from a chair could be used for these components. Measurements are evaluated according to the criteria of these components if they happen between events for start and end of a movement of the inhabitant. Validity criteria for the components walking there and walking back include: a walking distance d larger than a minimum distance $d_{min}^{walking}$ (4), a deviation in step lengths sl lower than a defined threshold sl_{max} (5) and an average walking speed v above a threshold v_{min} in order to ensure continuous movement (6), a number of detected steps s above a minimum number of steps s_{min} in order to exclude unnatural gait patterns (7), and a measurement for unstraightness of walking st not exceeding a maximum threshold st_{max} in order to exclude walking around corners (8). These criteria are defined in formulas 4 to 8:

$$f_{walking}^{distance}(x) = \begin{cases} 1 & d > d_{min}^{walking} \\ \frac{d}{d_{min}^{walking}} & otherwise \end{cases} \tag{4}$$

$$f_{walking}^{step_length}(x) = \begin{cases} 1 & sl < sl_{max} \\ \frac{sl_{max}}{sl} & otherwise \end{cases} \tag{5}$$

$$f_{walking}^{speed}(x) = \begin{cases} 1 & v > v_{min} \\ \frac{v}{v_{min}} & otherwise \end{cases} \tag{6}$$

$$f_{walking}^{steps}(x) = \begin{cases} 1 & s > s_{min} \\ \frac{s}{s_{min}} & otherwise \end{cases} \tag{7}$$

$$f_{walking}^{straightness}(x) = \begin{cases} 1 & \middle| st < st_{max} \\ \frac{st_{max}}{st} & \middle| otherwise \end{cases} \tag{8}$$

Quality Criteria for Turning. Turning is the component of TUG between the components walking there and walking back. All measurement between the end of a movement and the start of a movement in nearly the opposite direction should be validated. Turning has three quality criteria: The first criterion defines that the angle between the step vector of the first step within the turning and the step vector of the last step α should be above a certain threshold α_{min} and below a threshold α_{max} which ensures a nearly full turn of at least 160° to 220°. There should be no forward movement i.e. the distance walked d should not exceed a certain threshold $d_{max}^{turning}$. Additionally, in order to separate turning from standing, the duration of the turning $t_{turning}$ between the first and the last step of the turning should not exceed a duration threshold $t_{max}^{turning}$. These criteria are defined in formulas 9 and 11:

$$f_{turning}^{angle}(x) = \begin{cases} 1 & \middle| \alpha_{min} < \alpha < \alpha_{max} \\ 0 & \middle| otherwise \end{cases} \tag{9}$$

$$f_{turning}^{distance}(x) = \begin{cases} 1 & \middle| d < d_{max}^{turning} \\ d_{max}^{turning} & \middle| otherwise \end{cases} \tag{10}$$

$$f_{turning}^{duration}(x) = \begin{cases} 1 & \middle| t_{turning} < t_{max}^{turning} \\ \frac{t_{max}^{turning}}{t_{turning}} & \middle| otherwise \end{cases} \tag{11}$$

Quality Criteria for Sitting Down. Sitting down is TUG's last component. It starts as soon as the inhabitant stops walking in front of a chair and ends with the inhabitant making contact with the backrest of the chair. Measurement in between the events for end of a movement and contact to the backrest of a chair should be evaluated. The only validity criterion for this component is that sitting down should be a continuous movement i.e. a maximum threshold t_{sit}^{max} for the time between the end of the movement towards the chair and the contact with the backrest t_{sit} should not be exceeded 12:

$$f_{sitting\ down}^{continuous}(x) = \begin{cases} 1 & \middle| t_{sit} < t_{sit}^{max} \\ \frac{t_{sit}^{max}}{t_{sit}} & \middle| otherwise \end{cases} \tag{12}$$

5 Experiment

An experiment has been conducted in the OFFIS IDEAAL living lab in Oldenburg, Germany. Besides va-lidating the general feasibility of the presented approach to validating measurements according to given criteria, the experiment had two aims: (1) to proof that worse measurements lead to worse validity

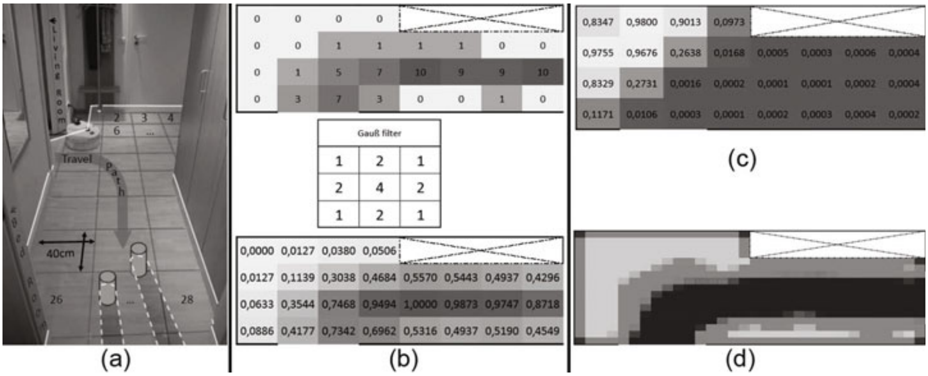

Fig. 2. (a) Experiment setup and schematics; (b) top: data collected during first measurements, middle: Gaussian filter matrix, bottom: filtered data; (c) calculated safety value for each field, higher means safer; (d) density map of safety criteria with high resolution, lighter color means higher safety

scores and that the defined criteria may be used to proof validity of assessments (at least from a technical perspective) and (2) to get a first idea on how sensor placement influences the quality of measurements for walking assessments. It has to be clearly stated that the experiment was not designed to provide sufficient data to ultimately say whether the proposed approach works in any situation or to infer general rules or patterns to say which circumstances provide the best assessment results. Within the experiment we focused on evaluating the TUG components "walking there" and "walking back". This is due to the fact that the robot can only detect start and end of these two components by using only its equipped sensors. However, in the future a mobile robot may detect the other components of TUG as well by utilizing sensors placed into the environment e.g. attached to a chair. Sensor measurements were recorded from different posi-tions within the floor of the living lab using a laser range scanner mounted on a mobile robot while a participant crossed the place on a single path. The presented quality criteria for walking there and walking back were then used to evaluate the measurements for these assessment components. Figure 2(a) shows the experiment's setup within the living lab's floor. The available area accessible by the mobile robot was divided into 28 fields having a size of 40x40cm which is approximately the size of the mobile robot used. During the experiment the robot was moved from one to the next field while its laser range scanner was always pointing towards the center of the room. For each location three measurements were taken (movement from the living room to the bed room) while the robot recorded the movement using its laser range scanner.

5.1 Methods

The mobile robot used is the PekeeII (Wany Robotics, France) which is equipped with a Hokuyo URG-04LX laser range scanner. The scanner measures distance to objects by emitting light and measuring the time taken for those signals to return to the scanner. The device has a scan angle of 240°, 120° to each side, a scan time of 100ms, and minimum and maximum range of 20 and 4000mm. Its accuracy is between 10mm and 1% of the measured distance. Parameters used within the quality criteria formulas 4 to 8 for walking were computed using an enhanced version of the approach to computing self-selected gait velocity from range measurements presented in [12]. The distances walked and the walking velocities are outcomes of the original approach. The number of steps taken was computed using a similar approach to the one presented by Pallej et al. [11]. Thereby, in opposite to our previous approach the distance measurements are no longer used to compute only the approximate position of the center of gravity of the walking person but the position of both legs is computed separately. Using the computed positions of both legs within each measurement set, stance and swing phase of the gait can be computed. Measurements belong to the same stance phase if the forward movement compared to the previous position is below a certain threshold. Within the experiment a threshold of 20cm was used. The mean of all coordinates belonging to a stance phase are the approximate foot position within the corresponding stance phase. A similar approach is taken to compute the position of the foot during the swing phase except that a certain distance threshold has to be exceeded. Each stance phase represented a step s. The length of a step is the distance between two consecutive foot positions of the same leg. The measurement for straightness of walking st is the sum of distances of all stance phase positions from the direct walking path of the inhabitant. The walking path is the vector between the center of gravity of the inhabitant within the first and the last stance phase detected. While evaluating the defined quality criteria, empirically determined thresholds were used. The minimum walking distance $d_{min}^{walking}$ was set to 2000mm. Regarding TUG this distance should be 3m but like in many household of elderly people our living lab merely has a straight path with a length of 3m or longer. In order to ensure continuous walking and to exclude standing still while walking the minimum average walking velocity v_{min} was set to 0.5m/s which is even below the walking velocity of people aged 80 years and older [23]. The maximum deviation in step length sl_{max} was set to be 400mm. The deviation in step lengths sl was set to be the mean value of the standard deviations of the left and the right legs' step lengths. The minimum number of valid steps s_{min} to detect was set to five steps. The maximum distance in mm a person should in sum differ from a straight walking line st_{max} was 500mm which ensures a rather straight walking.

5.2 Results

The computed parameters s, sl, v, d, st and their scores according to the corresponding score functions 4 to 8 are shown in Table 1 for each field (the order of numbering can be found in Figure 2(a)). A score of 1 means that the criterion for validity is totally fulfilled. All scores below give the percentage of reference value reached. The total validity score is computed using Formula 1.

Table 1. Validity Criteria and Score for Experiment

#	**Steps** s **(score)**	**Step Length Deviation** sl **in mm (score)**	**Speed** v **in m/s (score)**	**Distance** d **in mm (score)**	**Unstraightness** st **in mm (score)**	**Validity score**
1	9 (1.00)	264.99 (1.00)	0.69 (1.00)	1729 (0.86)	402 (1.00)	0.9729
2	6 (1.00)	123.66 (1.00)	1.29 (1.00)	1801 (0.90)	331 (1.00)	0.9801
3	4 (0.80)	127.94 (1.00)	0.69 (1.00)	1031 (0.52)	54 (1.00)	0.8631
4	12 (1.00)	576.76 (0.69)	0.85 (1.00)	2375 (1.00)	880 (0.57)	0.8523
5	7 (1.00)	659.88 (0.61)	0.89 (1.00)	2041 (1.00)	596 (0.84)	0.8890
...	...	...	...	...	...	...
16	10 (1.00)	729.28 (0.55)	0.82 (1.00)	2198 (1.00)	790 (0.63)	0.8363
17	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0.0000
18	7 (1.00)	218.37 (1.00)	0.50 (0.99)	1386 (0.69)	524 (0.95)	0.9279
...	...	...	...	...	...	...
28	9 (1.00)	645.56 (0.62)	0.66 (1.00)	1888 (0.94)	300 (1.00)	0.9128

Results show that using the proposed quality criteria most fields get rather good validity scores. This is basically due to the fact that the floor is a good room for mobility assessments since a person has to walk rather straight to get from one to another room and since the experiment's setup was designed to have as many valid measurements as possible.

However, our experiment had two aims: (1) to prove that worse measurements lead to worse validity scores and that the defined criteria may be used to show the validity of assessments (at least from a technical perspective) and (2) to get a first idea on how sensor placement influences the quality of measurements for walking assessments. Regarding our first aim it can be clearly stated that the defined quality criteria can be used to separate measurement with good assessment results from worse results. All measurements which did not fulfill the defined criteria where ranked down by the proposed approach. Additionally, the scores may be used as a measure of confidence for how much was missing to be an all valid assessment.

Regarding the second aim of getting a general idea of how sensor placement influences the computed scores no general guidelines or patterns could be found yet. Looking at certain fields' scores some influencing factors can be inferred. The first field is placed in the most left corner of the room. The participant entered the room right in front of the robot and walked straightly away into the bed room. The robot detected 9 steps, a small deviation in step lengths of only 26cm, a rather slow walking speed of 0.69m/s, and found an unstraightness of 40cm. The only criterion not fulfilled is the minimum distance walked which is only 1.7m. This is because the participant walked diagonal to the door frame into the room and was thus only measured starting from the end of field 15 on which is only approx. 1.7m away from the bed room. Another good example is the forth field which is located in the most right side of the floor. The place enables the robot to detect the participant even before she enters the room. Therefore, as many as 12 steps and a total distance of more than 2m was computed. However, since the test person walked a curve from the living room right towards the bedroom and an unstraightness of 88cm was detected, the measurement got a rather low score. The same effect can be observed for most fields that enabled the robot to look into the living room. The only field which got a score of 0 is field 17. This can be explained by the fact that the inhabitant had to walk over the robot and thus no continuous walking path could be detected. In summary, we can say that the experiment has proven that measurements which promise bad assessment results are ranked down by the proposed criteria. Regarding influence of sensor placement on computed scores no clear guidelines or patterns have been found yet. Results of the experiment do not provide a sufficient data base to enable a robot to find position for good assessment results before measuring.

6 Discussion on Safety

One point is to achieve the best mobility assessment result, but the other point is the safety aspect. The safety of robots is a critical point in all areas of application [24]. To reflect this point in this paper, we have defined safety criteria for the assessments. To be able to compute the safety criteria we used a learning database from the first gait measurements. First we divided the rooms in 40x40cm wide rectangles. The measurements were made in the IDEAAL living lab of OFFIS [25] (Figure 2(a)). The dimension from 40cm per each raster was chosen because of the diameter of 38cm of the mobile service. If a field is hit by a foot, the 'hit value' is incremented. Then a Gaussian filter is used to compute the probability of being hit for each field. To get comparable values the data is scaled to 1. An example for the first data set is show in Figure 2(b). In succession of these preparation steps, we now used the safety formula 13 to compute the optimal observation position of the robot regarding safety aspects:

$$s_i = \frac{1}{1 + e^{\left(\gamma \tanh\left(r_i + \underbrace{\frac{1}{n_i}\sum_{j=0}^{n_i} r_j}_{stumbling\ factor} - \underbrace{\frac{1}{k_i}(\sum_{k=0}^{k_i}(1-r_k))^2}_{avoidance\ factor}\right) + \delta\right)}} \tag{13}$$

We used three different parameters. The first parameter r_i indicates the probability that the person hit this field depending on the first measurements. The second parameter is the 'stumbling factor' that increases with the hit value of the field (the more the person uses the field or its neighbor fields, the higher the probability of stumbling if the robot uses that field). The third parameter is the avoidance factor. It shows the chance that the robot can avoid a collision with the elderly. In this first version we used only directly connected 'escape fields', in the next iteration also the diagonal field can be considered. Then the values were normalized into a range from zero to one, which can be seen in Figure 2(c). These safety criteria will be matched with the quality criteria of the mobility assessment. The results point out a save and high quality assessment point (OOL), from which the future measurements could be ideally started. To react on changes, these criteria will be periodically updated with the newest data from the assessments. In the next iteration it is also planned to make a finer grid of the room to get more possible OOL's. An example is shown in Figure 2(d) which is based on the same data with a higher resolution.

7 Conclusion

Mobility is one of the most important factors influencing an independent lifestyle and perceived quality of life. Especially elderly people suffer from impaired mobility and require care only due to mobility problems. Therefore, estimation of remaining mobility is an essential part of each geriatric assessment. Within clinical environment mobility is assessed using various assessment tests among which the Timed Up&Go is the most frequently used. Bringing assessments to the domestic domain could enable physicians to provide more early diagnosis, to prevent acute incidents or to further monitor patients during rehabilitation at home. However, assessments at home will be performed in non-standardized environments and under unclear circumstances. In order to infer clinical decisions from domestic assessment results quality criteria are required which tell health care professional how reliable those assessment results are.

Within this paper we have presented a novel approach to qualitatively evaluate domestic assessment results according to a set of quality criteria defined. The approach is based on the idea that classical assessments are divided into various components which are monitored in daily live separately and are later on recombined to complete assessment tests. We have defined quality criteria for the components of the TUG assessment test.

A conducted experiment has shown that the proposed criteria can be used to distinguish between measurements which promise good and bad assessment results. Computed scores may also be used to tell approximately how much is missing to reach a valid assessment data base. Results could not yet be used to infer a set of standardized rules or a pattern for presuming which sensor placements provide good assessment results.

Another important aspect for domestic environments is safety. The patients' safety has to be guaranteed throughout the whole assessment and becomes especially important when assessments are performed using mobile robots' sensors which may be an obstacle. Regarding the safety criteria we have shown that the first version of our algorithm computes results that are quite close to our expectations. The resulting robot positions seem to be relatively safe in view of not creating an obstacle to the user. Within the layout of our experimental room positions have been selected that are most likely not creating a tripping hazard.

Future work includes conducting another experiment whose aim will be to infer general rules or patterns to enable mobile robots or scientist (placing sensors) to find optimal sensor placements before recording measurements. Additionally, we will work on the combination of safety aspects and quality considerations into one combined approach and to find a tradeoff between those two important aspects in domestic assessment. An algorithm for recombination of recorded assessment parts has to be developed as well.

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User Acceptance of a Mobile LED Projector on a Socially Assistive Robot

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Abstract. A prototype of a LED projector module mounted on and carried by the humanoid robot NAO was iteratively developed in the KSERA project. It offers an additional visual information channel for the users (text, graphic, and video) by being able to come to the user where ever they are. Several mock ups were built to explore advantages and challenges of the mobile projector solution. Ten users, comprising six older persons and four experts from the care domain participated in laboratory tests to explore the user acceptance and expected usefulness. The novel projector solution was also compared with already existing solutions such as stationary screens. It could be shown that the novel solution of the mobile projector was well accepted bringing added value from the points of view of older persons as well as care experts. Challenges remain regarding suitable surfaces needed for projection and the currently limited brightness.

Keywords: AAL, socially assistive robotics, assistive technology, robot, COPD, mobile user interface.

1 Introduction

An emerging topic in Ambient Assisted Living (AAL) is the area of socially assistive robotics (SAR) which aims at developing suitable robots capable of supporting older persons in daily life. The goal of the EU-funded research project KSERA (“*Knowledgeable SErvice Robots for Aging*”) is to develop a SAR that supports older persons, especially those with Chronic Obstructive Pulmonary Disease (COPD), in their daily activities and care needs and provides the means for effective self-management of their disease [1]. In this way the independent and self-determined way of life and the overall quality of life can be enhanced.

The humanoid NAO robot developed by the French company Aldebaran [2] is used as robotic platform. It serves as an interface between the user and the system and is able to approach the users in their homes wherever they are. The robot system is embedded in a smart home environment which enables ubiquitous monitoring of the users’ activities and health status and of the environmental conditions.

As the used humanoid robot is very small (57 cm in height) compared to human beings it is not able to carry HCI devices such as a tablet PC which is often used in similar projects. To overcome this restriction a new module with a LED projector module mounted on the robot's back was developed in the KSERA project. The aim of this paper is to describe the prototype version of this projector module and the results of the first user tests carried out in laboratory conditions in order to explore the potential and user acceptance of the developed solution.

2 State of the Art

Following Feil-Seifer and Mataric (2005), socially assistive robotics (SAR) can be defined as the intersection of assistive robotics and socially interactive robotics [3]. This means that "SAR shares with assistive robotics the goal to provide assistance to human users, but it specifies that the assistance is through social interaction" (Ibid.).

Lee (2007) developed a ubiquitous display which is able to provide information wherever the user is [4]. The developed prototype consists of a NEC NP40J projector (weight 1.6 kg, brightness 2200lm), additional motors for pan and tilt adjustment, a battery for power supply (weight of 9 kg, 28 Ah) and DC/AC converter to provide AC 100V power for the projector. A Pioneer3-DX is used as robotic platform (Fig. 1).

Fig. 1. A photo of the ubiquitous display system on a wheeled robot (left) and its application marking an arrow on the floor for supporting navigation (right). Source: Lee (2007)

Park and Kim (2009) argue that Human Robot Interface (HRI) in most cases uses anthropomorphism and direct interaction, imitating the way people interact with one another [5]. As an alternative they present a projector on a moving robot which projects information on nearby surfaces (Fig. 2) and provides a relatively large area through which an indirect Graphical User Interface (GUI) based interaction can occur (Park et al., 2009).

Kwon and Kim (2010) compared efficiency in information transfer and user acceptance of a humanoid robot and a "projector robot" [6]. They found that for a museum guidance robot the humanoid robot version was rated superior in most categories including those of emotional quality and friendliness, but that the "projector robot" (which projected an avatar on the wall, see Fig. 2) was rated superior regarding understandability.

Fig. 2. Left: A proposed HRI platform with floor projection, Park et al. (2009). Middle and right: Museums guidance by (near) humanoid robot (middle) and by the projector robot (right), Kwon et al. (2010).

The company news [7] of February 2011 on the Aldebaran Website [2] presents a design study of the NAO robot wearing a projector on its head (see Fig. 3). No further details are provided about the projector and its technical specifications. Since the robot has to look in the same direction as the projection it cannot look at the user at the same time (see the two arrows in Fig. 3 and in Fig. 5). According to the KSERA user needs and scenarios this would be considered a serious drawback concerning robot human interaction.

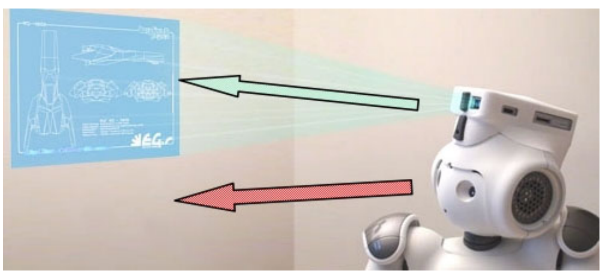

Fig. 3. Design study of Aldebaran (February 2011; source: [2])

3 KSERA Solution

The NAO robot [2] provides several built-in capabilities such as speech output, speech recognition, video cameras, audio input and output. In the framework of KSERA project the robot should be equipped with an additional capability to present visual information (text, graphics, and video) to the user. Currently no satisfactory wearable video communication is known for such a small size humanoid robot which shows the relevance of the KSERA solution described below. Carrying touch screen terminals for this purpose (as used in other projects [8], [9], [10], [11]) is not appropriate as the robot is not strong enough to carry standard terminal equipment and is not tall enough to present it using smart phones / PDAs at a suitable height to a sitting or standing user. Table 1 provides an overview of the comparison of the developed KSERA solution with existing devices.

Table 1. Pros & Cons – The LED projector vs. existing equipment. Mobile usage and support in case of emergency are expected to be the most innovative areas.

	TV set (with Set Top Box)	Stationary touch screen	KSERA mobile LED projector
Coping with different ambient brightness levels	Yes	Yes	Limited
Mobile usage ("following / approaching user")	No	No	Yes
Stationary usage	Yes	Yes	Yes, (e.g. robot sits on table)
Proven technology	Yes	Yes	No
Support in case of emergency (robot approaching user)	Limited	Limited	Yes
User acquaintance	Yes	No	No
Disappears if not needed	No	No	Yes
Innovation Potential	Low	Medium	High

Fig. 4. KSERA prototype of LED projector (left) and mounted on the humanoid NAO robot (middle and right)

Using other equipment already available in the users' home (e.g. TV set, stationary touch screen devices) is an option but is considered a complementary approach and not a standalone solution. A significant advantage of the robot over stationary devices is its mobility which allows it to approach the users wherever they might be in their homes (Table 1).

The vision of the KSERA approach is to provide the humanoid robot the means to project visual information with a LED projector carried by the robot. This allows overcoming the challenges named above while still enabling the robot to directly approach the users in their living area (Fig.5). Additionally, the KSERA approach aims at a flexible and open solution which allows presenting the visual information also by using other equipment (e.g. stationary devices) complementary to using the mobile LED projector.

Fig. 5. KSERA mobile projector approach for a humanoid robot. LED Projector mounted on the back of the robot allows NAO to look at the user while projecting on the wall.

Table 2. Technical data of the developed LED projector module used as part of KSERA system as mobile output channel

Specification	Remarks
Physical dimension	
Weight	430g
Size	35*80*150 mm (+ 45 mm for mirror and ext. antenna)
Mounting mechanism	
Position on robot	On NAO's back
Mechanism for fixation	Magnets for easy and quick mounting / unmounting
Autonomy of operation	
Internal battery	2 'Kokam single cell 1500HD 20C' 1500mAh, 3.7V
Power supply (charger)	12 V DC; 2 A
Connectivity	Wireless USB (Devolo Vianect Air TV)
Range	Up to 5 m free line of sight
Operation time	About 1h
Projection	
LED projector	Samsung SP-H03
Brightness:	30 ANSI Lumen
Resolution	WVGA (854 x 480 Pixel)
Contrast	1,000:1
Content	Text, graphic, video
Focus	Manual focus
Projection area	Wall, image size: 37x53 cm2; height above floor 50 cm
Distance	1.0 m (for fixed focus); with a range of 0.9 m to 1.1 m
Brightness on wall (without projection)	Brightness: < 180 lux (measured horizontally, 90 degrees to wall)
Ambient brightness	< 250 lux (measured vertically towards ceiling, while direct artificial lighting of room switched on

The specification of the developed prototype module (see Fig.4) is given in Table 2. Based on the user needs gathered in the KSERA project the LED projector offers the ability to present visual information as follows:

- Pre-recorded videos, e.g. physical exercise videos;
- Text and pictograms, e.g. weather forecast, various reminders; and,
- Video communication.

The information itself is provided by the KSERA intelligent server; also the timing of the beginning and end of projections is controlled by the KSERA state machine using a REST based interface. The projector component takes care for the visualization of the information to be shown to the user.

4 Methodology

The content of the laboratory tests comprised information transfer from the system to the user, social interaction and access to the functions of the smart home. The laboratory test partially relied on simulation techniques, mainly *Wizard of Oz* [12] which allows for test user acceptance and for gathering user feedback by simulating parts of the not yet completed integrated KSERA prototype system.

The laboratory test focused on the LED projector approach as an additional output channel gathering user acceptance and comparing it with existing devices and mock-ups (e.g. stationary screens such as a TV set, touch screen based systems) and on assessing the access functions of the smart home (e.g. fan, window opener, light). Both quantitative and qualitative methods were used to explore the users' and experts' experiences, opinions and ideas regarding the LED projector solution and the estimated potential and added value of the envisaged system and system modules, respectively.

4.1 Setting of the Test Environment

A laboratory was furnished to resemble a living room. The space had a couch (for the test person) and a couch chair (for the test leader), a coffee table, white walls suitable for projection, a second table with a stationary screen on it, objects and mock-ups to be controlled via the smart home, and the NAO robot equipped with the LED projector module on its back. Adjacent to this laboratory environment a separated space served as a technical control and monitoring room. In this area a researcher controlled parts of the system manually. This is called Wizard of Oz which is a methodology initially used by J.F. Kelley where test persons interact with a computer system which actually is steered by a human being [12]. According to Kelley the users may or may not be informed about the steering by the human wizard. In our experiments the users were informed about the Wizard of Oz approach.

The NAO robot was equipped with a German language synthetic speech output. It was connected to a laptop via a wireless LAN router. On the laptop a custom made software allowed the researcher to manually move and steer the robot using the keyboard. Additionally, it was possible to manually trigger (a) speech output and (b) visual output via the mobile LED projector (c) visual output on the stationary screen and (d) manual control of the smart home.

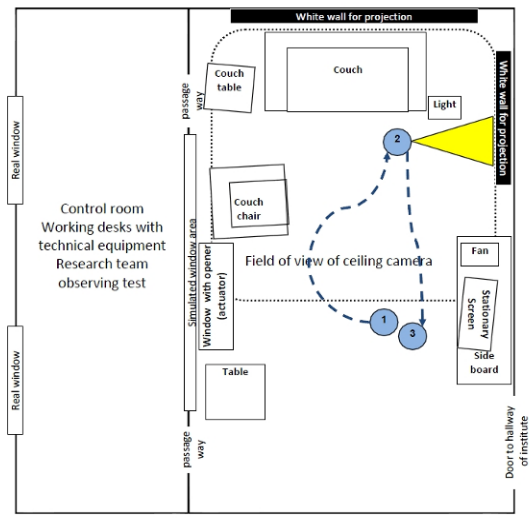

Fig. 6. Layout of the laboratory space with the position of mock-ups for user tests and expert demonstration

The laboratory space (Fig. 6) faces a noisy street. Prior to beginning the experiments the windows and the shutters were closed to avoid direct sunlight and the artificial light (fluorescent lamps on the ceiling) was switched on for constant illumination of approximately 250 lux. No air condition system was available in the laboratory. On hot summer days the room temperature with closed windows reached 28-30 degrees Celsius. The high temperatures were a discomfort for the participants and increased the probability of the robot overheating while walking.

4.2 User Involvement

The end users and experts were recruited from an existing pool of users from other assistive technology and AAL projects. All recruited end users received information about the KSERA project, its aims and the details of the laboratory tests in advance. Those who agreed to participate in the lab tests received more detailed information from the test leader in writing and in person. A process for informed consent established in fortec's assistive technology projects was followed [13]. The participants received a modest compensation to offset inconvenience and travel expenses. In order to protect the privacy of the participants all users were assigned codes and the data collected were stored on a secured server.

Fig. 7. Multiple images of NAO approaching user (top: camera position 1, bottom: camera position 2)

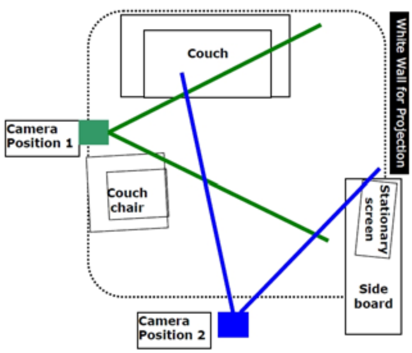

Fig. 8. Layout of the laboratory room with the 2 camera positions

4.3 Structure and Sequence of the Laboratory Tests

The structure of the laboratory tests followed the scenarios and use cases developed in the KSERA project [14]. The trials focused on the acceptance testing of the LED projector and on that of the access to the smart home functionality. All tests were video and audio recorded. The test leader collected the participants' responses in a semi-structured questionnaire. Additional notes were taken by the test leader and the Wizard of Oz. The different parts of the test structure are documented below:

- Welcome and introduction;
- Introduction to the KSERA project and description of the laboratory test;

- Process of informed consent; information, questions, and confirmation;
- Test phases:
  - Experiment 1: NAO (without LED projector) approaches user and delivers information via synthetic speech;
  - Experiment 2: NAO (with LED projector) delivers information via synthetic speech and LED projector;
  - Experiment 3: NAO (with LED projector) projects a video of physical exercise on the wall;
  - Experiment 4: NAO projects on the wall a pre-recorded video of call centre operators / relatives simulating a video phone call;
  - Experiment 5: User calls NAO and controls smart home applications with spoken commands;
  - Experiment 6: Delivery of information (as in Experiment 1, 2 and 4) on a stationary screen (in order to compare to LED projector).
- Open question addressing the experience of encountering the NAO; possibility for discussion and feedback by participants;
- Closing up.

The duration of the test was designed to be about 60 minutes. The shortest interview lasted 60 minutes, the longest exceeded 120 minutes. Altogether approximately 13 hours of interview material was collected. The laboratory tests were carried out in 2 phases, experiment 5 was added in second phase.

Pilot tests with university staff not involved in the project were carried out in order to validate and fine tune the design of the user lab test. Two of the pilot tests could be included in the collected data because the profiles of the pilot users met the inclusion criteria. Figure 7 shows sequential still pictures of the moving robot. These pictures were taken from two different positions in the laboratory (Fig. 8).

5 Results

5.1 Test Persons

A total of ten persons participated in the laboratory tests (test persons, TP). Six of the test persons were older adults (end users), some of whom had personal experience in providing care. Additionally four female care experts representing professional backgrounds in psychology (2), medicine (1) and occupational therapy (1) took part in the lab tests. The age range of the end users was 55-81 years with an average of 69.2 years and a median of 68 years. Four of the end users were male and two female. Four of the end users had been involved in a previous project of fortec focusing on the validation of a senior friendly web portal. Two of the four care experts had participated in an AAL project demonstration of a wheeled robot for persons with mild dementia. One test person worked as a volunteer in a Viennese retirement home. Limitations faced by test persons:

- one TP with an atypical hearing impairment wore a hearing aid; extreme hearing loss over 2kHz, had to concentrate on hearing speech;

- two TPs had slight hearing problems;
- one TP had very slight COPD; in no need of medication and without impairments affecting daily living;
- two TPs wore eye glasses (separate glasses for correcting myopia and pressbyopia);
- one TP had difficulty localizing a sound source.

Environmental settings: Blinds were closed and default light of the room was switched on in order to reduce the influence of sunlight. Illumination (ambient brightness) was measured in three locations: (1) on the projection area on the wall, (2) on the couch where the test person was seated, measuring vertically towards the ceiling and (3) on the sitting position of the test leader (chair) towards the ceiling, see Table 3. As can be seen in Table 4 illumination was in the range appropriate for a living room.

Table 3. Illumination (unit: Lux) during 10 lab tests measured in three different locations: wall (projection area), sitting position of test person, sitting position test leader

	Wall	Couch (test person)	Chair (test leader)
Mean	170.9	232.1	256.4
Standard deviation	23.5	31.8	15.3

Table 4. Recommended illumination in living areas (source: DIN 5035 part 2 as cited in http://de.wikipedia.org/wiki/Wohnraumbeleuchtung)

Rooms in the living area and activities	Recommended illumination (Lux)
Entrance area, hallway, staircase	10–50
Sleeping room, bath, living room, children's room	50–300
Activities in kitchen, work in household, personal hygiene, reading, writing	300–1000

5.2 Synthetic Speech and Projection Output

Overall, the quality of the built-in German synthetic speech output (NaoQi Version 1.10.44 with German text-to-speech software package '*asr-ged_1.0-r1_i386.deb*') of the robot was rated as sufficiently good. One person experienced difficulties in hearing the speech output. Another person stated that the voice should be more personal regarding pronunciation and prosody.

The additional visual information projected on the wall was rated as a very useful enhancement of the spoken information. According to the test persons, understandability and recognizability were improved when more than one output channel was used due to the fact that the visually presented information was available longer than the spoken output (see Table 5). They considered the visual information to be beneficial in noisy environments, such as in situations with background noise, and especially helpful for persons with hearing impairments.

Table 5. Perceived understandability of information provided by NAO with speech output (Experiment 1) and by NAO with speech output *and* LED projector (Experiment 2). Metrics used: Was the information provided understandable? (Yes – Partially – No)

Understandability of information is given in case of	Yes	Part.	No	Total	Yes	Part.	No	Total
Speech only (Exp. 1)	21	2	1	24	88%	8%	4%	100%
Speech & projector (Exp. 2)	28	1	0	29	97%	3%	0%	100%

Challenges for the projector solution included the need for a projection site on a suitable wall close to the user. Some test persons mentioned the limited size, brightness and sharpness of the projected information as problematic. According to the care experts, finding suitable projection surfaces in the fully decorated homes of older people is likely to be one of the main issues.

5.3 Projecting a Physical Training Video

The intention to motivate the end users for regular physical exercise was considered in principle very positive by most of the end users and care experts. One older adult who was already in the habit of standing up every 20 minutes for some physical activity objected to the idea of any additional support. Despite rejecting the idea this participant admitted to knowing somebody else with limited physical capabilities who would significantly benefit from such support.

One of the care experts thought that such a system would motivate her to more regular exercise. Everyone reported knowing at least one person who would benefit from the physical exercise video. While the majority of the participants found the quality of the projected video sufficient for understanding the presented information, some participants called for improved sharpness and better contrast (see Table 7). The mobility of the projector solution was rated as useful since the KSERA system could also follow the users and motivate them wherever they happened to be.

5.4 Projecting a Videophone Call

The capability of the robot projecting a video conference was considered very interesting by the participants. Some users had already had positive experiences with conventional video conference systems, such as Skype on their PCs. In ranking the uses of video conferencing for communication with friends and relatives, and for emergencies were highest followed by communication with other partners, such as physicians (Table 6). The perceived quality of the projected (moving) image was lower than that of the projected still images (see Table 7).

Table 6. Estimated importance and usefulness of video call capability (statements of users and experts combined, total: 10 persons)

Application of video communication	High	Medium	Low	N/A	Total
Case of emergency (e.g. a fall)	7	-	2	1	10
Communication with friends / relatives	9	-	-	1	10
Communication with "official" partners, e.g. physician, social services, city administration	6	2	-	2	10

Table 7. Perceived sufficient quality of image projected by NAO with LED projector for text and graphics (Experiment 2) and for video (Experiments 3 and 4). Metrics: Image quality sufficient? (Yes – Partially – No)

Clearness of projected image is sufficient in case of	Yes	Part.	No	Total	Yes	Part.	No	Total
Text & graphic (Exp.2)	21	7	1	29	72%	24%	3%	100%
Video (Exp. 3 & 4)	7	9	1	17	41%	53%	6%	100%

5.5 Comparison with Stationary Device

A mock-up of a stationary terminal (simulating familiar equipment such as a TV set and touch screen terminals) was part of the laboratory tests and it was used to deliver similar information as the mobile projector. The quality of the images portrayed on the screen of the terminal was considered better than the quality of the images projected on the wall. All but two of the subjects considered a stationary device useful and complementary to the KSERA system. Three persons were of the opinion that a stationary device would suffice for the KSERA system and that the mobile robot could be left out. For most (i.e. 6 out of 10) participants the main shortcoming of the stationary device was its inability to come to the users. Therefore the stationary device cannot deliver all the services that the mobile robot is able to provide to the end-user (see Table 8). The larger size of the projection and the ability to come to where the user is was seen as a superior feature of the mobile projector approach.

Table 8. Comparison of stationary device and NAO (statements of users and experts combined, total 10 persons)

Stationary platform	Yes	Partially	No	N/A	Total
Could be used a meaningful addition in KSERA	7	1	2	-	10
Can do everything the mobile projector can	3	1	6	-	10

An acoustic signal was given by the stationary device before showing a message. This was rated as useful by most persons but they disliked the specific acoustic signal used and recommended using another one.

5.6 Controlling Smart Home

Participants considered both the steering of the NAO robot via spoken commands and the possibility to control devices in the environment very useful and important. The simulation of the speech input using the Wizard of Oz methodology worked well: A few times the human wizard triggered the NAO to say "I did not understand!" and the test persons reacted by repeating their spoken commands as if a real speech recognition system had failed to understand the command.

In a "real" implementation of the voice control an additional level of spoken confirmation by the user might be needed in order to reduce the number of false positive detections. This would make the usage more complex and time consuming for the user but would avoid too high expectations regarding the performance of speech controlled systems [15]. Nevertheless, the test participants stated that even this type of a solution would be useful and important for them.

6 Discussion

The presented prototypes and mock-ups were well accepted by the end users and care experts in the laboratory setting. Most of the subjects stated that the additional visual output channel increased comprehensibility. Participants considered this important in particular for messages with somewhat more complex content (e.g. calendar, schedule of the day with multiple appointments) as the prolonged visibility brought significant added value compared to speech only output.

The presented ability to play video recordings for physical training was also rated high. Several ideas and proposals were made for further useful applications, including cognitive training, stress reduction training, and COPD information.

The ability of the KSERA system to provide video phone calls (presented as simulated video conference projecting the moving picture of the dialogue partner to the wall next to the user) was rated very high for all three applications (in case of emergency, for communication with friends or relatives and for communication with physician). A new application was proposed using a mobile video connection to support volunteers who regularly visit older persons in care institutions. Participants recommended specific 'tele-consulting' timeslots where physicians communicate with their patients on videophone.

Overall the test participants rated the quality of the projected image (brightness, sharpness, size) on the wall as high with regard to still pictures and text. With regard to moving images (physical exercise video, simulated video call) they also rated it high: however, some test persons requested a significant improvement of the sharpness of the video. The fuzzy quality may have been caused by the sub-optimal quality of the video presented and not necessarily by the projection itself.

The majority of the test participants considered the mobility of the NAO robot an important added value of the KSERA approach. Additionally, they stated that a stationary terminal (similar to TV set, touch screen PC) would make sense as a complementary component in the intended KSERA system. Nevertheless they also said that such a stationary terminal would not be able to deliver all those services and added values that the mobile robot is able to.

The home control design and simulated speech control was also rated high. Even in case that "real" word recognition systems would need an additional level of asking the user for confirming the commands before actually starting an activity it was considered to be acceptable.

Our objective was to gather user feedback to the novel projector module prototype and corresponding concepts. Based on the chosen methodology of simulated tests the comments gathered from the users provide valuable information but are limited in several dimensions. Firstly, in the framework of the used simulation methodology it was not possible to realistically position the robot's head orientation towards the test participants for enhancing Human Robot Interaction.

Secondly, while the KSERA integrated prototype will offer the possibility to monitor whether the user is looking towards the surface of the projection or not and in this way can provide flexible ways of attracting the user's attention, this was only possible in a very limited way during the simulated user tests.

Thirdly, most of the test participants had not previously experienced assistive robots and were therefore fascinated by the NAO robot used in the experiments. They not only interacted and commented on the mobile projector module but also with the robot itself. This may have influenced their perception.

Some of the material presented was not optimal (e.g. the pre-recorded video for the physical training exercise and the simulated video phone calls had low resolution). This also influenced the participants' feedback. Some comments of the test participants, for example the request to improve the brightness of the video may have been caused by the sub-optimal material rather than by the projection system.

A further limitations faced was the low brightness of the used projector (30 ANSI lumen). Using blinds at the windows and artificial light in the test room a realistic environment could be set up but it was at the lower limit of ambient brightness recommended for real living areas. Based on the technological improvements it is expected that better projectors will be available in near future.

It can be summarized that the simulated laboratory tests were very well received by the end users and care experts. The levels of user acceptance, user interest and user engagement were high in particular with regard to the mobility aspects of the projector, the multimodal presentation of information (speech and visual), the video communication, and the smart home interaction.

7 Conclusion

A prototype unit of the LED projector module was developed in the KSERA project. Laboratory tests with six end users and four care persons took place in a partially simulated setting and displayed a promising level of user acceptance and perceived usefulness of the system in daily life. Added value is seen by older persons and care experts in the mobility of the projector module. This was emphasized by comparing the mobile solution with mock-ups based on conventional stationary solutions for communication and smart home control.

The developed projector unit used in the laboratory tests was duplicated. Three units are now available and they will be evaluated with older persons and persons with COPD in different countries of the KSERA consortium as part of the integrated KSERA demonstration system. Additionally, work has started to extend the current LED projector prototype module by adding a real video call capability replacing the simulation mode which was used during laboratory tests described in this contribution.

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Part III:
Activity Recognition

Different sADL Day Patterns Recorded by an Interaction-System Based on Radio Modules

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Abstract. In this contribution different behavior patterns of different people are being analyzed. They are recorded by a system with small units based on a microcontroller and radio modules. Due to the demographic change, there is a need in Germany for systems that give elderly people the opportunity to live an autonomous life for as long as possible. There is a great demand of supporting systems that are able to ensure medical safety for these people. In order to determine the health state of a person an obvious choice would be to draw conclusions from the behavior patterns which can be deduced from the ADL (Activities of Daily Living). Different technologies are available for recording ADL. Some of them are presented in this paper. Following that, the system "eventlogger" will be introduced and the interaction of patients, mapped in a geriatric day hospital, and the resulting behavioral patterns, will be analyzed.

1 Introduction

In Germany, as well as in all other industrial nations, new challenges in the care and health systems will have to be met, due to the change of age distribution. In an ageing society there are more and more elderly people in need of care on the one hand and less young people who work on the other. This results in higher financial burdens for the social systems as well as the need for more personnel. For these reasons, along with the desire for autonomy, there is the wish to enable elderly people to live in charge of themselves and autonomously in their own home. In order to give these people security as far as their medical treatment is concerned an early diagnosis of old-age illnesses is essential.

5% of the people over 65 and 40% of those over 90 suffer from dementia for example [1]. Alzheimer dementia is usually a chronic illness characterized by a reduction in mental performance and memory recall and the implications this has for everyday activities (ADL) [2].

In order to test ADL there is a choice of standardized questionnaires like the Barthel Index for example [3]. This index describes an activity such as going to the toilet as follows: "*Patient is able to get on and off the toilet, fasten and unfasten clothes, prevent soiling of clothes, and use toilet paper without help. He may use a wall bar or other stable object for support if needed. If it is necessary to use a bed pan instead of* *a toilet, he must be able to place it on a chair, empty it, and clean it. Patient needs help because of imbalance or in handling clothes or in using toilet paper”* [4]. Besides defining the ADL for the diagnosis of dementia, watching the ADL can also illustrate the course of an illness and successful therapy. Thus ADL scales are being increasingly used as a criteria for the choice of therapy. Hence comes the wish to have an objective and automated method of defining the ADL at hand.

For initial tests it would be far too time consuming to map all the activities described in the Barthel index with the aid of a technical system, and thus the “simple ADL” (sADL) was introduced [5]. Here, from the interaction with an object (e.g. a toilet) the resulting sADL can be deduced.

In this article the first results from implementing the system referring to [6] shall be introduced. For this the day time profiles of different persons were observed and evaluated. Fortunately nearly every profile correlated to a specific person.

2 State of the Art

As already mentioned, the ADL are nowadays found using ADL scales according to the Barthel Index, in order to determine the autonomy of a person. Here data is collected by asking questions about the ability to carry out daily routines. The questionnaire is filled out by the patient if possible, or by a relative or nurse.

The subjectivity is one of the greatest disadvantages. [7] verified that a pure patient survey by the doctor is not significant. The Barthel Index scores surveyed by the patients` nursing staff were therefore compared to the direct interviews of the doctors. There were significant differences, probably due to the embarrassment of the patient on the one side and to the subjectivity on the other. [8] also published a study in which they used different kinds of data (patient, nursing staff, relatives, doctor) to determine the ADL scales. As a result, it is determined that the source of information for determining people’s extent of activity is not interchangeable and that patients often overestimate their functional performance, whereas external observers often underestimate the activities. Another disadvantage of these ADL scales is, that they are usually applied only when a person is already in treatment. Thus at the onset of the disease the gradually deterioration cannot be recognized. However, it is generally known that the therapeutic results are better the sooner a disease is detected.

In research there are various projects with the aim of developing a system which is able to detect different ADLs automatically. Here, one method is to define areas of frequent use with the aid of infrared motion detectors [9-13]. These motion detectors are either installed in the living area or connected via radio transmission and batteries without using cables. As the areas under surveillance can only be roughly defined, additional sensors, such as door contacts are used to attain more exact information. Another approach is based on video systems. Certain areas of the living environment were recorded like in [14] and then evaluated using algorithms. In order to attain better results the video systems are also combined with switches [15] [16] as well as with RFID-Systems [17] [18]. A lot of research work is done using RFID-technology. [19] for example, developed a glove and, later on, a wristband equipped with RFID-readers [20]. The readers have a range of about 10 cm. [21] also developed a mobile RFID-system that was worn around the wrist and had a similar range. [22] [23] were able to significantly increase the recognition of ADL through combination with an acceleration sensor. A gap in the recognition of the RFID-system can be filled by using the acceleration.

A disadvantage of the infrared motion detectors is that they cannot differentiate between two different human beings. Sometimes there are even problems in differentiating humans and pets. Video systems have problems when covered and with different kinds of lighting. What is more, the acceptance of these systems is doubtful. By adding further technologies the disadvantages of video systems can be reduced, the installation work and the complexity of the data involved however will increase significantly. RFID-systems prove not to be useful in everyday life, due to their short range.

3 Materials and Methods

The system "eventlogger" which is used here, is based on adjustable and local communication between radio modules and was already presented already in [6]. The basic approach is a blueprint of human communication. The volume of the voice is always chosen in such a way that the persons you are talking to are being reached and not the complete room. This approach was already implemented in robotics via infrared [24]. The transmit power of the used radio modules with 2.4Ghz can be adjusted to different ranges. The modules are transmitting their own ID with the adjusted power. The transmit power can be adjusted in 64 steps with the following values:

$$-33\text{dBm} < TP < 0\text{dBm} \quad (1)$$

With the hardware used in this setup we get ranges r_{sADL} from about 0.3 to 40 meter. Hence the usual measuring of the RSSI (Received Signal Strength Indication) is not used.

The transmitting of the own ID is done with a frequency of f_t=2 Hz. At the same time the radio modules are able to receive the ID of other eventloggers with a frequency of 0.5 Hz and a duration of 501ms. Hence, two Eventlogger (m,n) with different positions P in a room, have three different states:

$$P_m \begin{pmatrix} x_m \\ y_m \\ z_m \end{pmatrix}; P_n \begin{pmatrix} x_n \\ y_n \\ z_n \end{pmatrix}; \; r_{sADL_m} > r_{sADL_n} \quad (2)$$

State 1: Both Eventlogger are outside of the transmit range of the other:

$$|P_m| - |P_n| > r_{sADL_m} > r_{sADL_n} \quad (3)$$

State 2: Only one Eventlogger can receive the other:

$$r_{sADL_m} > |P_m| - |P_n| > r_{sADL_n} \quad (4)$$

State 3 Both Eventlogger can receive the other:

$$r_{sADL_m} > r_\text{n} > |P_m| - |P_n| \quad (5)$$

The event E_m is generated when the distance of both Eventlogger is smaller than the transmit range r_{sADLm}:

$$|P_m| - |P_n| < r_{sADL_m} \Rightarrow E_m \tag{6}$$

If the Event E_m not detected anymore, a $sADL_m$ is saved. The advantage of saving the event at the end is having an efficient usage of the memory and an easier understanding of the raw data. That is why the ID, the starting time and the duration is saved.

$$sADL_m := [ID_m, k_{on}, k_{off} - k_{on}] \tag{7}$$

K_{on}: starting time; k_{off}-k_{on}: duration

The sADL are saved on the flash memory of the Eventlogger or on a separate Micro-SD-card. In addition every name of each ID is saved for a better allocation of the data.

As already mentioned, the data can be read out as a text file directly from the SD-card. Furthermore the data can be sent to a base station connected to a PC or the HomeCareUnit (HCU) [25]. There they are saved in a sql-database and visualized via different illustrations [26]. There is a day view and a detail view of the sADL. The day view shows the total duration of the interactions to other Eventlogger (Fig.2). The detail view shows the duration of each interaction in a time diagram (Fig. 3).

The hardware setup of the eventlogger is designed as followed: The central unit is a nanoLOC AVR module which consists of an atmel microcontroller (2) and a radio chip (1) as well as a chip antenna. To determine the proper time a Real-Time-Clock (5) is connected via I2C. The data can optionally be stored on an external flash memory or on a mini SD card (4), which are connected to the microcontroller via SPI. Additionally a motion sensor (3) is integrated to be able to determine states of motion [27] in the future. Movements of objects such as the cup could also be observed. The power supply (6) is assured by a lithium-ion battery with 250mAh, a charge controller and a voltage converter (Fig. 1).

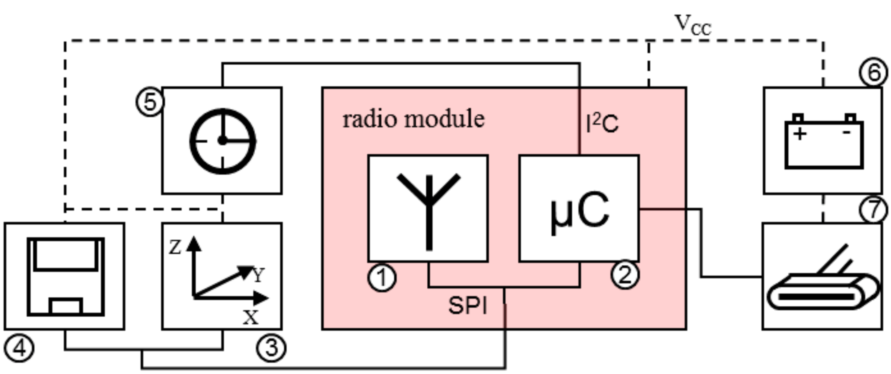

Fig. 1. Hardware setup eventlogger 1)Radio chip, 2)Microcontroller, 3)Accelerometer, 4) Flash-memory/SD-card, 5) Real-Time-Clock, 6)Battery, 7)Connector

4 Experiment

The system that is introduced here was installed for evaluation at the Gerontopsychiatric Day Clinic of the TU-Munich (Clinic for Psychiatry and Psychotherapy) for a period of two month. At the Gerontopsychiatric Day Clinic people with affective and dementia illnesses are treated over a period of four to eight month, applying a multimodal therapy program.

The following objects or rooms were equipped with an eventlogger:

- kitchen
- conference room
- nurse's room
- men's toilet and wash basin
- ladies' toilet and wash basin
- entrance (one inside one outside)
- occupational therapy room
- PC
- physiotherapy room
- 5 mobile eventlogger for distribution to patients

For the evaluation 5 volunteers (four students and a 60 year old person) each wore an eventlogger in the rooms of the day clinic and they were each accompanied by a person keeping minutes. They had the task of noting the time that the actions took place. In the end the data noted by the eventlogger and the minutes were compared. It was shown that a sensitivity of 80% with a weighting of short events detection can be reached within this experimental setting. Also a sensitivity of 79.9% and a specificity of 99.2% with a weighting of long events detection could be reached [5].

In addition different patients in the day clinic wore an eventlogger for a couple of days each. From 28 persons 82 day profiles were produced. At first we will only look at the first two weeks during which 12 people produced 41 day profiles. Fig.2 shows a day summary, Fig. 3 a day profile.

Using the profiles attained in this way, it was first determined whether they were specific to an individual person. 41 day profiles were shown to a Doctor over a period of two weeks and he arranged them without any further information. The Doctor assigned the profiles to 12 people, which was the exact number. Important criteria for the distribution were: Frequency and time of going to toilet, interaction with others, general conduct.

In a further step the persons were characterized according to their day profiles and this was compared to the notes of a medically trained observer.

As expected, the basic behavior of an individual can easily be ascertained. Partly, it can be deduced from the whereabouts of a person. Thus it is implied that when a person is in the kitchen or conference room, he or she is sitting down. If the entrance is logged and then there are no new events for some time, it is implied that the person was outside and has most likely taken a walk. Furthermore the number of interactions with other people is also an indicator for the basic behavior. Staff, like for instance the nurse or the occupational therapist, could be recognized due to their individual daily

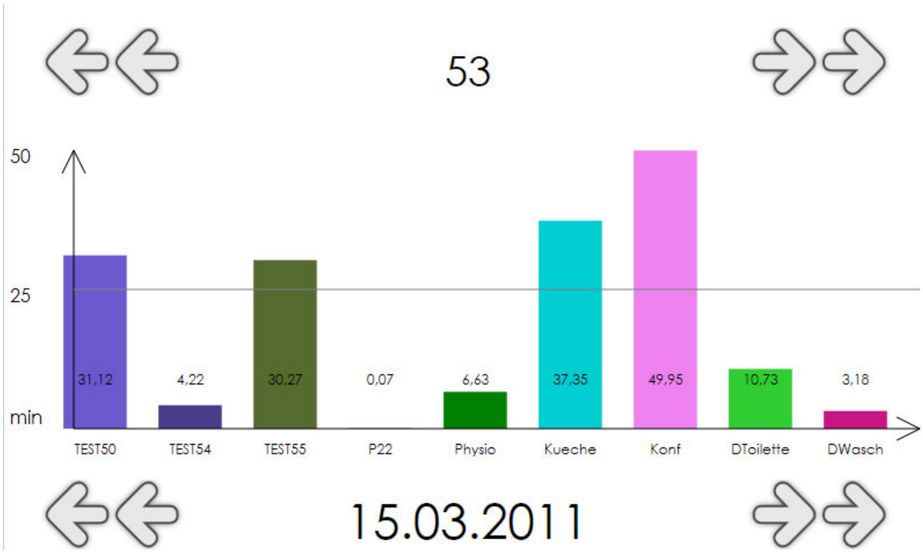

Fig. 2. Summary of the day view of proband 5

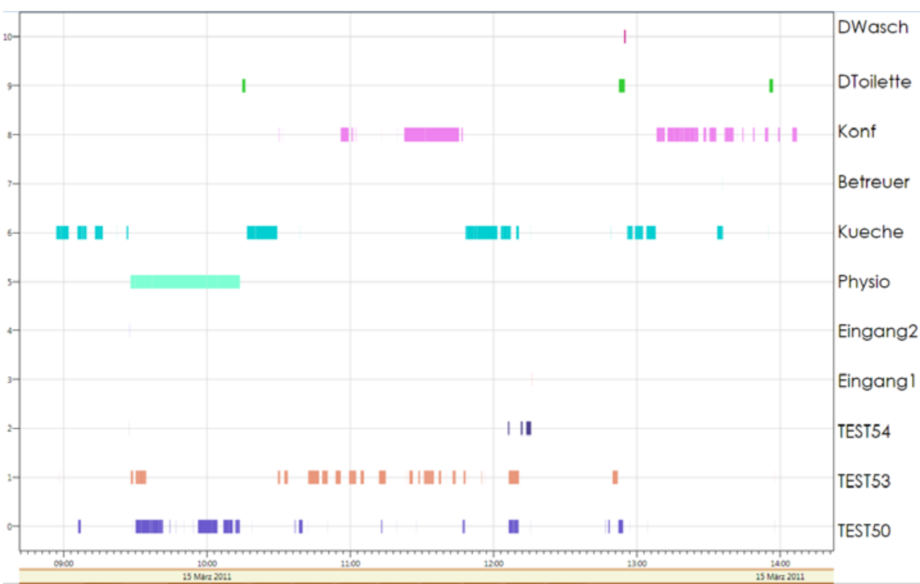

Fig. 3. Day profile of proband 5 in detail view

Table 1. Interpreted information by a doctor from the day profile taken from the eventlogger versus the notes form the clinical practice

Pers.	day profile taken from the eventlogger	notes form the clinical practice
1	basic passive behavior	sits much at the same place
	elderly female proband	middle aged woman
	about 1x per day on toilet	
	4th day 1 hour on the PC	proband has been told to work on the PC for 15min
2	more active basic behavior	old but very agile
	2x walk outside alone	
	Walk outside with others	social excursion
	at least 3 times per day on toilet	has been told to go to toilet 4x
3	active basic behavior	young, mobile, moving rapidly
	maybe a smoker	smoker
	walks with proband 11	
	goes to the toilet at different times	The information about going to toilet given by the proband and recorded by the eventlogger differ
4	basic passive behavior	inactive
		no (no suggestions)
	approx. 3x toilet per day, extended periods	
	little contact with other	mentally severely impaired
	often goes home early	proband gets nervous after lunch, is taken home earlier
5	1 day 7x toilet	aconuresis
	2 day 4x toilet	order only 4x toilet
	in the kitchen and conference room a lot	severely impaired
	together with person 10 a lot	
6	2x a day longer time on the toilet	
	longer talk with the carer	sociable
	much contact with other persons	sociable, helpful
	walks outside	mobile, fit
7	carer (between supervisors room, kitchen, conference room)	nurse
	accompanies patient in the cellar for physio-therapy	

Table 1. *(continued)*

8	short recording lot occupational therapy -> occupational therapist	 occupational therapist
9	often at the entrance -> smoker spends a lot of time in the conference room longer walks alone rarely goes to toilet ->drink more?	smoker insecure in the group young, likes to be alone onset of Alzheimer
10	approx. 3 times per day toilet often takes a walk outside	 likes go for a walk dementia
11	 Rarely goes to toilet	little intellectual restriction mainly depressive young, healthy
12	many contacts with other people	sociable, friendly onset of dementia

routine. Nothing, however, could be said about the current course an illness was taking, due to the short periods of mapping over only a few days. This however is the aim, with the aid of the system that is being introduced here, the daily routine of a person and possible changes over a longer period of time should be detected. Aconuresis (incontinence of the bladder), as in person 5 could easily be noticed. In addition individual persons were given certain tasks that could be verified with the help of the eventlogger. Person 5 for example was asked to go to toilet exactly 4 times, and this was done correctly. Person 1 was asked to work at the computer for 15 minutes. This was done more than to standard, by working there for an hour.

5 Discussion

The day profiles of individuals have been shown to differ to such an extent, that a Doctor can differentiate them, at least if there is a limited number. As this analysis is very time consuming however, it will be necessary to develop an algorithm that enables changes in a person to be detected automatically. Here it will be important to allow a learning phase in which the "normal" behavior can be determined. It only takes a few days to discover basic kinds of behavior and conditions such as aconuresis by looking at the rate at which the toilet being used. Due to the limited number of day profiles however it is not possible to draw conclusions, as to whether slow changes within the system would be recognized by a Doctor or whether an algorithm would detect them. For this more experiments will be necessary. The results so far, however, seem to be very promising. What is more, the system can, contrary to other state of the art devices, be easily integrated into living areas and comes at a realistic price.

6 Conclusion

The newly developed system eventlogger uses radio modules with an adjustable range and serves as a recorder for sADL. The first trial runs at the Gerontopsychiatric Day Clinic of the TU Munich have shown that the recorded sADL and the then resulting day profiles can be differentiated due to their individuality. What is more, personal basic habits and abnormalities (in using the toilet) can be detected. The trial run that was made here shows that the behavioral patterns of the patients are individual to such an extent that a differentiation is possible. The next step will be to develop an algorithm which will do this automatically and is able to detect changes. Furthermore it shall be tested whether the system can be used as an aid to train people with aconuresis. Such a training program aims at prolonging the time intervals between each visit to the toilet (e.g. to two hours). To do that, the eventlogger will indicate the end of a time interval via an LED lighting up (if in the meantime going to toilet has not been registered) and thus “allows” a visit to the toilet. By this setting a training effect can be reached that gradually prolongs the intervals between going to toilet and will thus support a behavioral therapy treatment of aconuresis.

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Smart Meter: Detect and Individualize ADLs

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Abstract. Smart meters offer a low-cost, simple, and unobtrusive method to design monitoring systems for the detection of emergency situations in homes. The aim of this paper is to automatically detect the activity (Activity of Daily Living, ADL) of occupants based on such data. The approach trains a Semi-Markov-Model that describes the daily use of appliances, such as domestic appliances, sanitation, and heating system. Human habits are detected within the Semi Markov Model and rated by a similarity measure that calculates the probabilities for the ADL executed by the occupant based on the appliances he uses. This rating influences the probability for the ADL and permits model adaptation to individual user behavior. Considering the timeline of appliance usage, the probability estimations of each model state allow individualized and situation depending conclusions about the ongoing activity of the occupant.

1 Introduction

Senior citizens want to stay self-determined in their accustomed homes. But, they are afraid of accidents caused by their impaired physical and mental skills. Ambient Assisted Living (AAL) focuses on developments to help in such situations. For Example, the European project PERSONA [1] develops an open platform to provide a large variety of AAL-Services including early risk detection. The Project SELBST [2] develops a small mobile computer called Personal Digital Assistant (PDA)also to provide AAL-Services not only usable at home. These projects out of many use a monolithic system based on several expensive sensors. While this provides substantial data for analysis, it often does not cope with the financial situation of most AAL users. Monitoring systems for AAL should not only reliably detect emergencies, they also should be affordable to buy, install, and operate. Furthermore, they should avoid stigmatization and be invisible or related to other uses as they will be otherwise refused by seniors.

The German project AUTAGEF [3] reuses commercial smart meters for electricity, water, and gas. Smart meters have to be installed per edict in the EU [4] and, therefore, will be broadly available in future. Smart meters are unobtrusive to the occupants as they are usually installed in hidden spots and are functionally related to metering. Thus, there is no need to install devices in the apartment and no fear of stigmatization. The costs of smart meters are rather low as they are a mass product. Only the monitoring service needs to be financed. A potential business model is discussed in [3].

Known approaches for activity monitoring can also be used to analyze smart meter data. Floeck & Litz used inactivity diagrams [5] based on more than 25 different sensors for each apartment. Inactivity diagrams are useful to detect emergencies causing a lack of activity such as falls or fainting. But, they consider only the absence and occurrence of sensor events. The content of the signal is ignored. Many important information is ignored that could be used to detect more and more specific critical situations.

Yin & Bruckner [6] analyze the content of the signals with Hidden-Markov-Models based on occupy sensors to generate a movement profile. But, still the real content of the activity is not deduced.

The project AAL@HOME [7] also uses Markov-Models to detect health critical situations. A sequence of different Relational Markov Networks (RMN) is used. Specific sensors and RMNs are defined for every disease. This requires expert knowledge of medical staff and a diagnosis or at least a speculation of the occupant's ailments.

With smart meters it is possible to detect the executed activity and its content. The consumption data can be analyzed to detect single home appliance used by the occupant. Wilken et al. [8] introduce a method for home appliance detection based on electricity consumption data. Every home appliance has its own unique consumption pattern and can be recognized with a 98% true-positive- rate. By analyzing the gas and water consumption, the use of the oven, shower or toilet can be detected. The chronological order of used appliances can be displayed by a behavior model and the executed activity can be deduced. These activities are called Activities of Daily Living (ADL, Chap. 3.2).

This paper presents how to train a behavior model based on smart meter consumption data to deduce the executed ADLs of the occupant. The ADLs are predefined on the base of available home appliances in the occupant's apartment. The ADLs will be redefined and individualized by training a Semi-Markov-Model. Based on that, health critical situations can be detected and help can be organized. Additionally the essential daily routine can be supervised and the amount of caring effort can be measured and the care can be supported by the AAL-system.

The following chapter describes the scenario of behavior modeling and the envisioned monitoring phases. The 3rd chapter introduces the initial phase, the used home appliances, and the ADL definition. The training phase is explained in Chapter 4. It includes the training of a Semi-Markov-Model (SMM) and its structural characteristics, which are rated by similarity measurement. The calculations of the training phase are explained in chapter 5. Particularly, the computations of the ADL probabilities are described in extensive examples as well as the rating of the structural characteristics of the model. This rating influences the calculation of the ADL probabilities and helps to individualize them. The results are critically discussed in the conclusion.

2 Overview

Each apartment is equipped with meters for electricity, gas and water. The consumption data is analyzed to detect the usages of individual electrical home appliances from electrical devices to sanitary appliances [7]. The resulting event series are used as input for the detection of daily profiles.

The AAL-systems workflow can be divided into three phases: the initial phase, the training phase and the application phase.

During the *initial phase* the types of smart meter and home appliances inside each apartment are defined. Furthermore the possible relations to the ADLs are analyzed, too. In the following *training phase* the behavior model and its structural characteristics are calculated. *Structural characteristics* are pattern of habits (ADL) of the occupant. These characteristics will be compared to the current consumption data to find abnormalities. This step is called the *application phase*. If abnormalities are detected, which may be caused by falls or fainting, an alarm message will be generated to organize help.

The detected ADLs can also be used to support home care. Knowing the ADL and their occurrence allows individualizing home care. A lack of ADL or changes in them may indicate changes in the health situation of the occupant.

3 Initial Phase

3.1 Home Appliance Definition

During the initial phase general information about the home appliances are gathered. This requires collecting the home appliances actually used in the apartment. Two groups of home appliances exist: mobile and static. Static appliances cannot be moved and are assignable to one room of the apartment. Mobile appliances can be used in any room, e.g. the vacuum cleaner or any kind of charger. Figure 1 shows a graphical user interface for the data acquisition. Each flag represents one room and contains a list of the appliances used in this room.

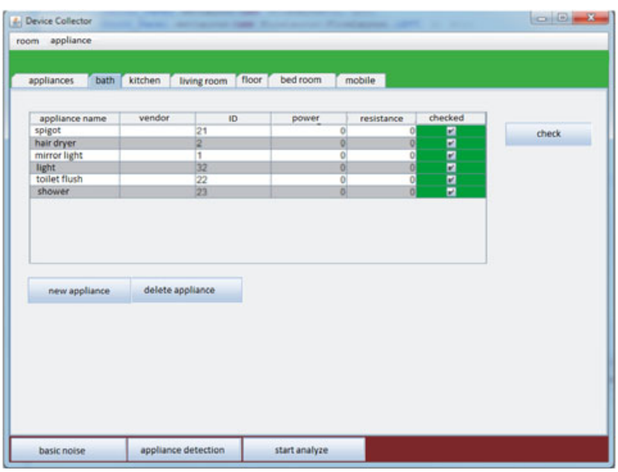


Fig. 1. Graphical interface for data acquisition: each flag represents one room with its home appliances

The graphical user interface allows to add („new appliance") or remove („delete appliance") appliances. It is also possible to measure the background noise („basic noise") for each smart meter. This removes the influence of all standby appliances from the further analysis. For each appliance the typical consumption characteristic is measured in the initial phase. These appliance consumption profiles are used to recognize the appliances during the training and application phase using approaches such as [7] for electrical meters and similar concepts for water and gas meters. Assuming that most appliances are unique and static in the apartment their assignment to rooms allows also to deduce the location of detected events. If appliances occur several times in an apartment and cannot be individually detected and localized in first place, the later steps in the approach will permit a stochastic assignment out of the context of the appliance used in the same time frame.

The introduced approach is not only suitable for smart meter. It is possible to define additional sensors (e.g.: occupancy sensors, RFID, temperature, comfort) to get more detailed information about the occupant's behavior and to increase the information value. The sensor lists can also be imported from automated system design approaches [9].

Table 1 presents an example of the equipment of a single apartment. The majority of appliances are located in the kitchen. It is recommended to register only the appliances frequently used, as scarcely used devices are hardly trained and will be treated as outliers. Not registered appliances are detected but ignored during the analyses.

Table 1. Equipment example of a single apartment

	Kitchen	Bath	Corridor	Bedroom	Living room	Mobile
Appliances	light oven fridge coffee maker toaster kettle spigot	light hair dryer mirror light toilet shower spigot	light telephone	light PC sewing machine extra light	light TV recorder music	vacuum cleaner charger

3.2 ADL – Activity of Daily Living

Activity of Daily Living (ADL) are essential routines every person executes. Two categories of ADL exist: Basic ADLs and Instrumental ADLs. *Basic ADLs* are those skills needed in typical daily self care. An evaluation would, in part, consist of bathing, dressing, feeding, transferring, continence and toileting [10]. *Instrumental ADL (IADL)* refer to skills beyond basic self care that evaluate how individuals function within their homes, workplaces, and social environments. Lawton & Brody [11] define eight different IADLs: use of telephone, laundry, shopping, mode of transportation, food preparation, responsibility for own medications, housekeeping and ability to handle finances. The research of this paper primarily focuses on Basic ADLs, because some IADLs cannot be detected by the smart meters (medication, finance) or take place outside of the apartment (transport, shopping). However, as the introduced approach can also be applied to other sensors, it may be used to recognize IADLs.

The Basic ADLs: feeding, bathing, transferring, going to bed and toileting can be directly detected by smart meters. Each ADL consists of a *set of actions* that are typically related to it and may occur in different temporal orders. For example, the ADL bathing relates to the actions: going to the bath room, washing at a basin, taking a shower, or using the tub. Each action now can further be *related to appliance(s)* such as the lights in the bath room or the tap at the basin, shower, or tub (differentiated by flow rate and duration) that are assigned respectively. However, each of these relations are *n*:*m* associations, where an appliance can also implicate different actions that imply different ADLs. The challenge now is to deduce the correct ADL from the appliance detected by the smart meters.

3.3 ADL-Appliances-Definition

The performed ADL should be deduced from the appliances identified by smart meters. Therefore, the appliances are first assigned by experience to typical ADL with a certain probability. In Table 2 the action flushing the toilet is assigned to three different ADL. With a probability of 70% it indicates the ADL sanitation. But, the toilet can also be used during cleaning the household or food preparation if some waste is disposed. The vacuum cleaner is only assigned to the ADL household as the occupant does not need it for something else.

The ADL appliances definition can be adapted individually. Therefore the occupant must give detailed information about it. For example a hobby handcrafter may use the vacuum cleaner while sawing wood to absorb the shavings. But, most of the time there is no adaption needed. The association between home appliances and ADL allows a preference calculation of the executed ADL. The calculation is explained in Chap. 4.4 .

Table 2. ADL-Definition for the appliances flush and vacuum cleaner

Appliance	ADL	Weight G_a, with $0 \leq G_a \leq 1$
Toilet Flush	Sanitation Household Food preparation Shopping, Telephone, Media	0.70 0.25 0.5 0.0
Vacuum cleaner	Household Sanitation, Food preparation, Shopping, Telephone, Media	1.0 0.0
…	…	…

4 Training Phase

4.1 Behavior Model

During the training phase the consumption data from the smart meters are logged and transferred into a behavior model formed by a Semi-Markov-Model (SMM). Afterwards the detection for structural characteristics within the SMM starts, which are representing the occupant's individual habits. They are used to refine the ADL application definition and to adapt the ADL definition even more precise to the occupant's habits by including the characteristics from the SMM into the probability calculations.

A *Semi-Markov-Model* (SMM) is used as behavior model, in which each state is defined by the set of active home appliances, which are either on or off. Accordingly, the currently active state represents a snap-shot of active appliances. Redundancies are not permitted. If the status of an appliance changes, then the model will transit into another state that corresponds to the new active appliances. Figure 2 illustrates an excerpt from such a SMM. First the light was switched on (ID 31), secondly the TV (ID 11) and later the telephone (ID 10). During the call the occupant turned of the TV and after finishing the call only the lights (ID 31) are still active. In [12] the SMM is explained in more detail.

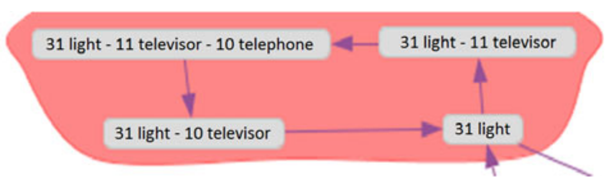


Fig. 2. Excerpt from the behavior model (SMM) representing the as-is situation of the home appliances

Each SMM has additionally an *idle-state*. The SMM is in this state if all home appliances are inactive (switched off) or if the occupant left the apartment. In Fig. 3 this idle-state is called "no Event" with ID 0. The idle-state exists in every SMM and thus can be used as entry point for each analysis. Each state logs the entry and exit times, which are used in Chap. 4 for further calculations. The states highlighted in Fig. 3 are assigned to the same room. Each color represents another room. For example the green highlighted states are assigned to the kitchen. Obviously most of the transitions are between states of the same room. Hence many ADL are limited to one room. For example: the sanitation usually takes place in the bathroom.

Inside the light red shaded region (bathroom) of the SMM in Fig. 3 similar structures (structural characteristic) occur. It seems as if they could be consolidated to a more generic structure.

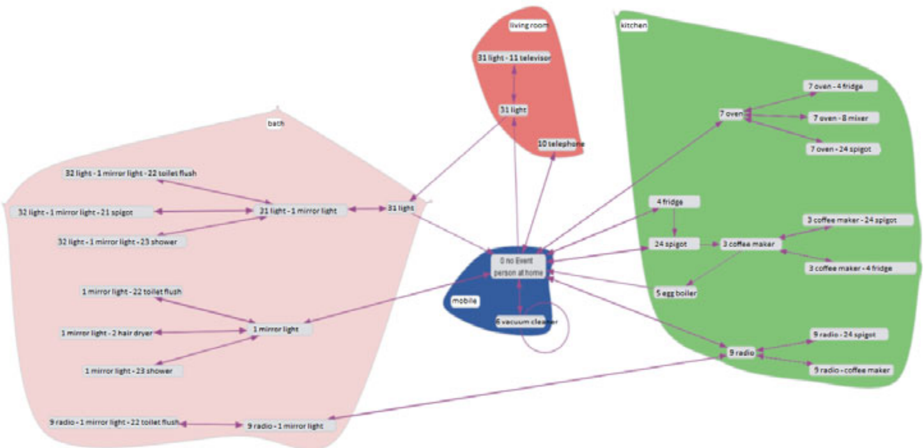


Fig. 3. Semi-Markov-Model illustrating the occupant‘s behavior. The highlighted regions allocate states to one room. The different underlines assigning states to ADLs: orange: sanitary, blue: household; red: food preparation; black: media; green: telephone; white: shopping.

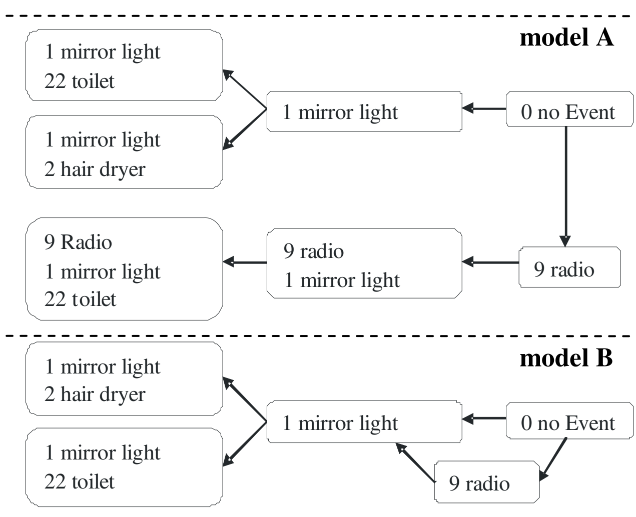


Fig. 4. Excerpts of two SMM displaying the same information in different perspectives. Model A contains all original measured paths while model B has merged these paths.

Figure 4 displays one example. Model A - in the upper part of the figure - represents the original version of Fig. 3. It basically consists of two similar series of sanitation actions once without and once with the radio on. Model B - in the lower part of Fig. 4 – combines these series into one model. However, model B results in inconsistencies with the measured states in Fig. 3. In example, the radio can never be active in conjunction with any sanitation action. Hence, states measured before get lost or may be falsified by consolidation. Therefore, the more extensive model was chosen as behavior model. This may result in a higher state space, but, as most appliance combinations do not occur in reality it usually is manageable.

4.2 Habits and Structural Characteristics

During the initial phase (Chap. 3.2.1) the home appliances where assigned to ADLs with probabilities. The probabilities describe how likely an ADL is executed given an active appliance. However, in most cases an appliance may be used for different ADLs. Then it is necessary to consider the set of active appliances and their order of usage to detect the ADL correctly. As the users often have specific habits to perform an ADL, they are often detectable as structural characteristics in the SMM using graph-theoretical methods. A detailed introduction in the topic can be found in [12]. The application of these methods to Fig. 3 results in the examples given in Table 3.

An *isolated circle* is a graph-theoretical circle of states with only one state having transitions to the idle state. The other states in the circle can only be accessed via this entry state. Circles usually indicate common habits of the user as the contained appliances are used only in this combination and context. A *non-isolated circle* has not such a strong distinctive meaning. It can be entered via several states and the timestamps have to be considered while analyzing the circle. The so called *dead end* is a special case of the isolated circle that consists of only two states. This structure is of particular interest, because of its frequent occurrence (Fig. 3) and represents strong habits of the user. A group of dead ends are called *star*.

The star is harder to detect as it needs to be differentiated which dead ends really belong to it and form a meaningful group. *Sequences* and *chains* are linear state series. Sequences represent stronger habits than chains, because chains contain small breaks between the usages of appliances, which were analyzed to be negligible. It is less important if sequences or chains are isolated or not.

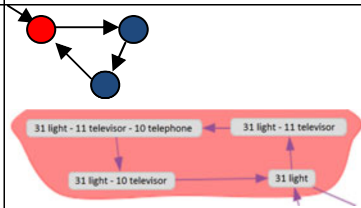
4.3 Similarity of Two Structures

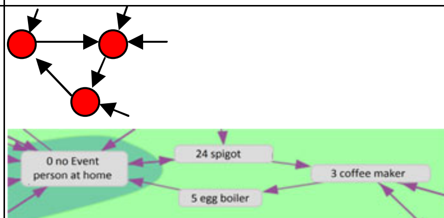
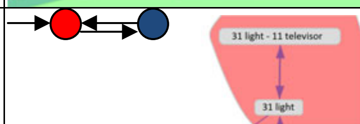
It was discussed in the last chapter that habits usually indicate certain ADLs and result in structural characteristics in the SMM. This indication will be evaluated by a significance criterion G_S of a characteristic structure S for any ADL structure a_i. The criterion evaluates the similarity of both structures between 0 and 1 from the weighted mean

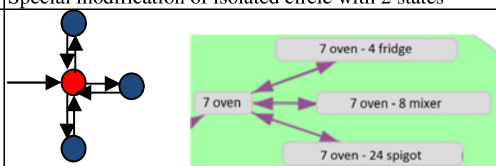
$$G_S = 0.6\frac{N_{mT}+N_{mZ}}{max\,(N_{T1}.N_{T2})+max\,(N_{Z1},N_{Z2})} + 0.1\left[1-\frac{N_{SA}}{N_{TA}+N_{SA}}\right] + 0.2[1-\delta_{Zt}] + 0.1[1-\delta_t] \quad (1)$$

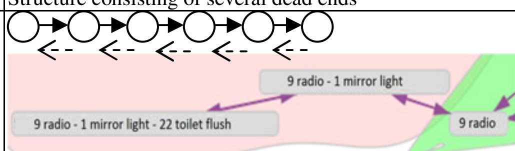
of the sub-criteria defined in Table 4.

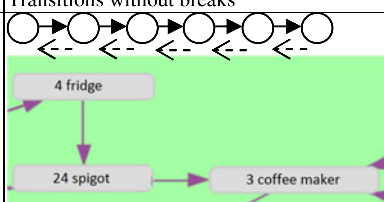
Table 3. Overview of structural characteristics of a SMM

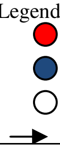
<table>
<tr><td>Name</td><td>Model extract</td></tr>
<tr><td>Isolated circle</td><td>

[1]</td></tr>
<tr><td>circle</td><td>
</td></tr>
<tr><td>Dead end</td><td>

Special modification of isolated circle with 2 states</td></tr>
<tr><td>Star</td><td>

Structure consisting of several dead ends</td></tr>
<tr><td>Sequence</td><td>

Transitions without breaks</td></tr>
<tr><td>Chain</td><td>

Transitions with “negligible” breaks</td></tr>
<tr><td></td><td>Legend:

entry state of the structure
structure state isolated
neutral state
transition</td></tr>
</table>

[1] Not an excerpt of Fig. 3.

Table 4. Sub-criteria to evaluate structural similarity

Sub-Criterion	Equation part
Similarity of two structures	$\frac{N_{mT} + N_{mZ}}{\max(N_{T1}.N_{T2}) + \max(N_{Z1}, N_{Z2})}$
Degree of isolation	$1 - \frac{N_{SA}}{N_{TA} + N_{SA}}$
Similarity of time intervals	$1 - \delta_{Zt}$
Similarity of timestamps	$1 - \delta_t$
- N_{mZ} number of matching states -N_{mT} number of matching transitions -N_{SA} number of entry and exit transitions -N_{TA} number of transitions without match: N_T - N_{mT} -N_T number of transitions -N_Z number of states -δ_{Zt} standard deviation time intervals between two states normalized to an interval of $0 \le t \le 1$ -δ_t standard deviation of timestamps, normalized to an interval of $0 \le t \le 1$	

The significance criterion of a structure G_S is calculation in relation to a comparison base (structure), e.g.: the whole SMM or a part of the SMM representing an ADL. The first considered sub-criterion is the *similarity of two structures*. It is calculated as the ratio of identical states and transitions in relation to their sum. The mapping of identical states is simple as they are uniquely defined by their set of active devices. The transitions are further uniquely defined by the tuple of source and target states. As states and transitions are the basic elements of a SMM, this sub-criterion is weighted highest with 60% within G_S.

The *degree of isolation* evaluates the variations in the transitions to enter or leave a structure. The value ranges from 0 to 1, while a lower value means additional transitions to enter or leave.

As described in Chap. 4.2 many structural characteristics demand an evaluation of timestamps. The evaluation of *timestamps* respectively *time intervals* are calculation via the standard deviation of matching states. The time data is normalized in a preprocessing step to fit the interval of [0,1]. The time intervals are rated higher than the timestamps, because human habits usually show similar patterns in the durations of actions, but not necessarily at exactly the same daytime.

4.4 Structural Evaluation of Occurring ADL

During the initial phase (Chap. 3.2.1) the home appliances where assigned to the ADL respectively the corresponding probabilities. The probabilities describe how likely an ADL was executed given the chronological order of used appliances. Chap. 4.2

deduced that some combinations of appliances intensify specific ADL and these combinations of appliances can be detected as structural characteristics of the SMM. The previous chapter introduced an equation to calculate a significance criterion of a structure G_S. Based on these facts this chapter introduces a method to assign the typical structural characteristics to a specific ADL and thereby adapting the significance criterion of a structure G_S to individual occupant's habits.

The significance criterion G_S (equation (1)) is calculated between a structure S and an ADL a_i. An ADL a_i are all states Z_i of the SMM where home appliances are active that were assigned to the ADL a_i and all transitions T_i between these states. The evaluation of this structure is calculated by the following algorithm:

For each existing ADL a_i do:

1. Compute the sets Z_i and T_i of a_i
2. Compute the sets Z_S and T_S as the number of all states and transitions of the structure S
3. Compute Z_m and T_m, with $Z_m = Z_i \cap Z_S$; $T_m = T_i \cap T_S$
4. Compute N_{SA} and N_{TA} of S
5. Compute δ_{Zt} and δ_t for all elements in $Z_{ü}$
6. Calculate G_S from (1) with: $N_{mT} = |T_m|$; $N_{mZ} = |Z_m|$; $N_{T1} = |T_i|$; $N_{T2} = |T_S|$; $N_{Z1} = |Z_i|$; $N_{Z2} = |Z_S|$

The calculation is explained for the example structure S shown in Fig. 4. The corresponding definition of ADL probabilities G_a are given in Table 5. The structure starts in the kitchen, where the radio was turned on. Then, the occupant enters the bathroom and activates the mirror lights to use the toilet. According to Tab. 5 the radio is only assigned to the ADL media. The mirror lights and toilet are assigned to the ADLs sanitary, household and food preparation. The challenge is to determine the ADL that was executed with the highest probability.

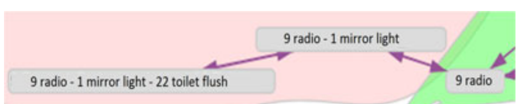


Fig. 4. Structural example from Fig. 3

The significance criterion G_S is calculated for each ADL with the algorithm given above. Tab. 6 lists the results for all six ADLs that occur in the whole SMM. N_{Z1} and N_{T1} present the number of states and transitions belonging to one ADL. $N_{Z2} = 3$ and $N_{T2} = 4$ of the example structure in Fig. 4 are independent form any ADL and remain constant. N_{mZ} and N_{mT} are the number of equal states and transitions between the ADL and the structure. The structure in Fig. 4 is an isolated structure, therefore N_{SA} will be set to 0. δ_{Zt} and δ_t will remain constantly 0.2 respectively 0.6 to simplify the comparison.

Table 5. Weighted allocation of appliances from the structure shown in Fig. 4 to the corresponding ADLs

appliance	ADL	Weight G_a, with $0 \le G_a \le 1$
Radio	media sanitary, household, food preparation, shopping, telephone	1.0 0.0
Mirror light	sanitary household food preparation shopping, telephone, media	0.6 0.2 0.2 0.0
Toilet	sanitary household food preparation shopping, telephone, media	0.70 0.25 0.5 0.0

Table 6. Calculation of each G_S for all possible ADL in reference of the structure in Fig. 4

	N_{Z1}	N_{T1}	$N_{ÜZ}$	$N_{üT}$	N_{SA}	δ_{Zt}	δ_t	G_s
Sanitary	15	16	2	2	0	0.2	0.6	0.377
Household	18	17	2	2	0	0.2	0.6	0.369
Food preparation	19	23	2	2	0	0.2	0.6	0.357
Shopping	2	0	0	0	0	0	0	0
Telephone	1	0	0	0	0	0	0	0
Media	6	8	1	0	0	0.2	0.6	0.343

The differences in the significance criterion G_S are not significant between sanitary, household, food preparation and media for the given example, even though, sanitary is strongest. Reason is, that each ADLs usually relates to several appliances such that only a small subset of appliances are used in a structural characteristic like Fig. 4. This renders the correct identification of the active ADLs difficult. The next chapter will introduce the selected approach using the calculated values for G_S.

5 Application Phase

5.1 Estimate Probable ADL

After successfully ending the training phase the monitoring system can start to detect abnormal behavior in the so called application phase. In this phase the currently measured data are compared with the trained SMM and its structural characteristics. If one structure of the SMM matches the current measurements, the previously in the training phase calculated G_S will be integrated in the estimation of the most probable ADL (PADL). The PADL values within the application phase which activity the occupant executes with highest probability. If a structure is only partly detected, than a new G_S will be generated for that part and used for calculations. For the estimation there will also be a calculation of G_S but this time between the current measurement and the trained structures. This time G_S refers to the ratio of current measurement and the trained structures. This G_S will influence the PADL.

The estimation of the PADL is explained by the event series of: r*adio* → *radio-spigot* → *radio* → *radio-mirror light* → *radio-mirror light-toilet.* The event series will be analyzed step by step in chronological order as they would appear online. With every new transition the PADL is recalculated.

First, it is detected that the radio was turned on. This results in a state with only one active appliance and the PADL is defined by the probabilities from initial phase. Table 9 lists the single calculations steps. In row one the state *radio* was detected and the probabilities G_a from the initial phase are inherited. The current PADL is media and printed in bold in the table. The next detected appliance is the spigot from the kitchen. Now two appliances are active in parallel and the SMM is searched for a trained structure matching the state series r*adio* → *radio-spigot*. The series matches a dead end structure in Fig. 3. Table 7 displays the G_S calculation from the initial phase for this structural characteristic.

Table 7. G_S-calculation for the trained structures from the initial phase: r*adio* → r*adio-spigot*

	N_{Z1}	N_{T1}	$N_{ÜZ}$	$N_{ÜT}$	N_{SA}	δ_{Zt}	δ_t	G_s
Sanitary	15	16	1	0	0	0.14	0.5	0.341
Household	18	17	1	0	0	0.14	0.5	0.339
Food preparation	19	23	1	0	0	0.14	0.5	0.336
Shopping	2	0	0	0	0	0	0	0
Telephone	1	0	0	0	0	0	0	0
Media	6	8	2	2	0	0.14	0.5	0.493

The G_a defined in the initial phase from both states are used to calculate an average G_{aAVG} for each ADL. The result in shown in Tab. 9, 2nd row, 4th column. The 5th row presents the recalculated PADL with respect to the G_S from recognized structures. For each calculation of G_{aAVG} the corresponding G_S is used as an intensification factor. G_{act} is calculated as follows:

$$G_{act} = G_{aAVG} * (1 + G_S) \tag{2}$$

The usage of the spigot changed the weight of the ADL media from 1.0 down to 0.75 and increased the ADL weights for sanitary, household and food. After closing the spigot only the radio remains turned on and the PADL are again the ones from the initial phase, because the SMM turned back to the state *radio*. Only the ADL media is still active.

Now the occupant moves into the bathroom switching the mirror lights on. The SMM transfers from state *radio* to state *radio-mirror light*. This partly matches the structural characteristic shown in Fig. 4 in two states. To represent this match of a sub-structure the G_S of the whole structural characteristic is modified. The new weight G_{Snew}, which also influences the recalculated PADL, represents the product of G_S and $G_{S'}$, which represents the structural match between the current structure (*radio* > *radio-mirror light*) and the whole structural characteristic. Table 8 summarizes the newly calculated $G_{S'}$ and Tab. 9 presents the resulting G_S values in the 5th row. The weight of ADL media decreases from 1.0 to 0.66 and the weights of sanitary, household, and food preparation increase up to 0.35, 0.12, and 0.12 respectively.

Finally, the occupant uses the flush in the example. Now all states of the characteristic structure (Fig. 4) match. Thus G_S from Tab. 6 can be directly used for the PADL calculation as provided by Tab. 9, last entry. The weight of the ADL media falls to 0.44 whereas the sanitary weight increases to 0.6 and is the new PADL. Alternatively, the occupant may execute with a weight of 0.21 also the ADL household or with 0.31 he is preparing food, while the radio is on.

The usage of weights makes it possible to estimate the most probable ADL (PADL). However, the focus on a single ADL limits the expressiveness of the model, as it does not permit that different orthogonal ADLs are executed in parallel. For example, the user may also listen to the radio and clean the flat at the same time, and thus execute the ADL media and household in parallel. A more precise evaluation might consider context knowledge such as time schedules. But, this requires human input.

Table 8. $G_{S'}$ calculation of the partly structure: *radio → radio-mirror light in ratio to the whole structure: radio → radio-mirror light → radio-mirror light-toilet flush*

	N_{Z1}	N_{T1}	$N_{ÜZ}$	$N_{ÜT}$	N_{SA}	δ_{Zt}	δ_t	G_S	G_{Sneu}
Sanitary	2	2	1	0	0	0.2	0.6	0.45	0.170
Household	2	2	1	0	0	0.2	0.6	0.45	0.167
Food preparation	2	2	1	0	0	0.2	0.6	0.45	0.161
Shopping	2	0	0	0	0	0	0	0	0
Telephone	1	0	0	0	0	0	0	0	0
Media	1	0	1	0	0	0.2	0.6	0.9	0.309

5.2 The Impact of G_S

G_S intensifies the weights of particular ADLs. If a previously trained structure occurs, even partly, the actual similarity G_{act} will increase. If no previously learned structure matches the current measurements, G_S has no impact at all.

G_S is introduces in Chap. 4.4 as a similarity criterion. It measures the likeness of one structure to a given ADL. Whereas one ADL is the part of a SMM, where all states and connecting transitions were added to the specific ADL during the initial phase.

If the structure is relatively small in comparison to the ADL, G_S also turns out to be quite small and if this structure in recognize during the application phase the factor G_S intensifies the weight of the PADL only a little. But, if the previously trained structure is relatively big compared to the ADL, it means the structure represents a major part of the ADL, G_S will majorly influence the resulting PADL. If the structure is recognized during the application phase, the corresponding ADL will be rated higher and the distribution of weights must be recalculated. The new PADL represents a more individual estimation of the executed ADL, because the individually trained human characteristics are now considered.

Table 9. ADL probability calculation during application phase in chronological order of currently measured events

Appliance	ADL	G_a	G_{aAVG}	G_{act}
radio	sanitary	0.0	0.0	0.0
	household	0.0	0.0	0.0
	food preparation	0.0	0.0	0.0
	shopping	0.0	0.0	0.0
	telephone	0.0	0.0	0.0
	media	**1.0**	**1.0**	**1.0**
radio → radio-spigot	sanitary	0.4	0.2	0.268
	household	0.2	0.1	0.134
	food preparation	0.4	0.2	0.268
	shopping	0.0	0.0	0.0
	telephone	0.0	0.0	0.0
	media	**0.0**	**0.5**	**0.745**
radio → radio-spigot → radio	sanitary	0.0	0.0	0.0
	household	0.0	0.0	0.0
	food preparation	0.0	0.0	0.0
	shopping	0.0	0.0	0.0
	telephone	0.0	0.0	0.0
	media	**1.0**	**1.0**	**1.0**
radio → radio-mirror light	sanitary	0.6	0.3	0.351
	household	0.2	0.1	0.117
	food preparation	0.2	0.1	0.116
	shopping	0.0	0.0	0.0
	telephone	0.0	0.0	0.0
	media	**0.0**	**0.5**	**0.655**
radio → radio-mirror light → radio-mirror light-toilet flush	**sanitary**	**0.7**	**0.43**	**0.593**
	household	0.25	0.15	0.206
	food preparation	0.5	0.23	0.312
	shopping	0.0	0.0	0.0
	telephone	0.0	0.0	0.0
	media	0.0	0.33	0.442

6 Conclusion

This paper introduced a method to train a Semi-Markov-Model based on consumption data from smart meters, such as electricity, gas and water. This SMM allows a deduction of the most probably executed ADL (PADL) by the occupant. Therefore, the home appliances were assigned a priori to common ADLs. The assignment was adapted to the human habits during the training phase by detecting and evaluating individual human behavior patterns. These patterns are utilized during operation by a similarity criterion to estimate the PADL individualized to the occupant's habits. The approach was verified on data examples collected by smart meters in a single apartment.

The introduced approach will be further extended to compare whole models with each other to enable trend analyzes of behavior models. Furthermore, the role of cycles will be analyzed. We assume that cycles are not only suitable to detect activities from event data, but may help combining single model structures to a more complex human habit. The SMM will be developed further to include a meta-model that connects the ADL-models with the apartment's rooms and other context information. To enable the improved detection of single ADLs as well as the execution of different ADLs in parallel such as listening to a radio and cleaning the flat.

The approach not only improves the detection of ADLs, uncommon behavior, and health critical situations. It also permits the individualization and optimization of home care based on the detection of user habits. This enables home care that is faster, easier, and addressing the needs.

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A Novel Indoor Localization Approach Using Dynamic Changes in Ultrasonic Echoes

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Abstract. In this paper a novel approach to continuous and unobtrusive localization of a person inside his or her domestic environment based on ultrasonic sensors is presented. The approach uses half rings with ultrasonic sensors mounted on the ceiling of the environment. The person's position is computed by analyzing the detected echoes of the available sensors. After distinguishing between echoes caused by the static environment and echoes caused by the person, only the last-mentioned echoes are utilized to determine the position. This position can then be used for further analyses such as mo-bility assessments or for providing location dependent services.

1 Introduction[1]

The demographic change poses many problems e.g. due to the decline of the care ratio. In the near future there will be less people paying taxes for financing the health care system while there will be more people requiring health services. Costs due to the high need of care of demented people [1] and their high fall risk [2] are two of the major factors influencing the proportionally higher costs to the health care system caused by elderly people. Dementia is an old-age disease with a worldwide prevalence of 4.7 % (6.2 % in Europe) for people aged 60 years and older. Due to the demographic change, the total amount of demented persons worldwide will increase from approx. 35.6 million people today to approx. 115.4 million people in 2050, i.e. the amount will nearly duplicate each 20 years [1].

In order to meet the increased challenges on the health systems, new approaches for delaying the need of care and for prevention of acute incidents like falls need to be developed. Long-term monitoring of mobility may provide the required means for supporting an earlier diagnosis and thus for initiating early prevention. This may help saving costs while increasing perceived quality of life for people concerned. Mobility impairments also have a high prevalence in dementia [3] and are an early indicator [4]. However, today's health systems often cannot exploit the possibilities of early

[1] The Lower Saxony research network "Design of Environments for Ageing" acknowledges the support of the Lower Saxony Ministry of Science and Culture through the "Niedersächsisches Vorab" grant program (grant ZN 2701).

diagnosis through mobility assessments. Today, health care professionals most often get in contact with affected people only after an acute incident or once the presence of a disease is already obvious to the layman. Additionally, they can only assess a person's health state in a proportionally small time frame while long-term assessments may provide more reliable and even more detailed insights. However, this would require remote assessment possibilities in domestic environments of people, which do not exist today.

Within this paper we present our first work towards a sys-tem for a continuous and unobtrusive indoor localization of a person in his or her domestic environment. This in-formation can then be used for a long-term mobility as-sessment by computing the gait velocity and also for sup-portive services such as a reminder assistant whose audible or visual output depends on the person's position. Furthermore, this localization can provide additional information for activity recognition [5]. The system consists of ultrasonic rings that are mounted on the ceiling of the domestic environment.

2 State of the Art

Several approaches to indoor localization have been developed utilizing different kinds of technologies. Some of these approaches require that the person has to carry some physical device or tag with him or her and analyze, for example, the received signal strength indication (RSSI) or the time of flight (TOF). These approaches also require user interaction like attaching, donning and charging. Our research is explicitly targeting older people with reduced cognitive capabilities, in particular demented people, wherefore systems that do not require user interaction and carry-on devices are clearly preferable. Brubaker et al. [6] deal with video based tracking of a person. However, due to privacy aspects people often do not want video cameras in their domestic environment. IR motion detectors installed in every room of the environment enable a room-precise localization. Large arrangements of pressure sensors can be used to locate a person when placed under the floor. Steinhage [7] introduced a system based on a smart underlay with capacitive proximity sensors consisting of conductive textiles. Since the spatial arrangement of sensors is known, a person walking over the surface can be located. Wan and Paul [8] developed an unobtrusive indoor tracking system based on ultrasonic sensors that are mounted on the walls of a room. The detected echoes are analyzed to determine the position of a person.

3 Localization System

The localization system developed by our team determines the position of a person inside his or her domestic environment by analyzing ultrasonic echoes. These echoes are emitted and detected by a number of ultrasonic sensors placed on a ring that is mounted on the ceiling. Echoes can either be caused by the static environment or by a person located inside the coverage of the ultrasonic ring. The localization system requires at least one ultrasonic ring for each room and can easily be adapted to different domestic environments because only the positions of the ultrasonic rings in the corresponding room coordinate systems are needed, which are available in a configuration file. In order to visualize the computed positions, the system also requires a 2D floor plan of the environment.

3.1 Hardware and Software Components

The ultrasonic ring is shown in **Figure 1**. 15 ultrasonic sensors, manufactured by Devantech Ltd. (Attleborough, Norfolk, England), are mounted on a polystyrene half ring with a diameter of 30 cm. 14 of these sensors are arranged in two circles on this ring. Because of the sensors beam width of 55 degrees each circle contains seven evenly distributed sensors, whereby the main propagation direction of the beam for each sensor has an angle of either 25 de-grees (inner circle) or 45 degrees (outer circle) to the normal of the ring plane, whereas the main propagation direction of the 15th sensor is parallel to this normal. These ultrasonic sensors use the I^2C bus for communication, which is furthermore connected to a USB port via two radio telemetry modules (USB to radio, I^2C to radio), also manufactured by Devantech Ltd. The localization software on the PC configures the ultrasonic sensors and the radio telemetry modules and receives the detected echoes from the telemetry module, which simultaneously triggers all sensors on the ring to send an ultrasonic pulse and subsequently collects the resulting echoes from each sensor. Additionally, the localization software also computes the position of a person by analyzing the measured first echo received by each ultrasonic sensor and then visualizes this position inside a 2D floor plan of the domestic environment.

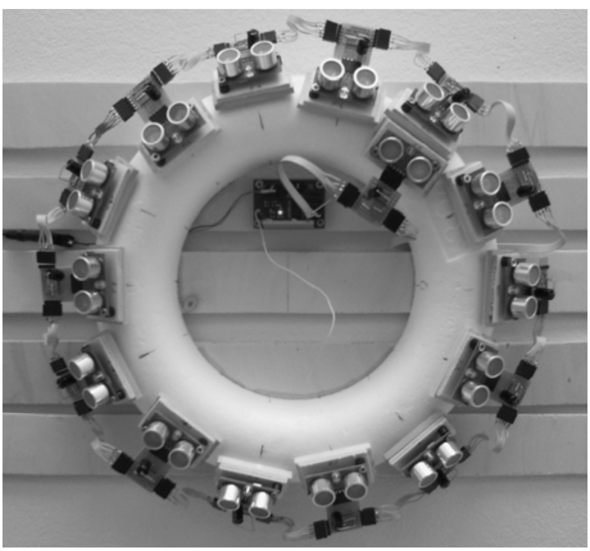


Fig. 1. Ultrasonic ring prototype with 15 ultrasonic sensors attached (bottom view)

3.2 Static Environment Detection

Both the static environment and a person present in the room can cause echoes that are detected by the ultrasonic sensors. The presence of multiple surfaces in the "field of view" of the sensor may cause multiple echoes to be received in response to a single pulse. Therefore, the system needs to distinguish between echoes caused by the static environment and echoes caused by a person. In order to achieve this, the system first determines the echoes in the "empty" room, i.e. with no person inside the coverage of an ultrasonic ring. Currently, the system produces and analyzes 1000 sequential echoes for each ultrasonic sensor for this learning phase. Unfortunately, due to the "noisy" nature of this technique, the static environment echoes of one sensor can vary, even though nothing in the room is moving. Therefore, the system takes account of up to three different echo times (distances) for each ultrasonic sensor as constituting static background echoes. **Figure 2** shows an example for detected static environment echoes of one sensor. In this case, the system will consider three different echoes for this sensor, namely the local maxima at 119 cm, 128 cm and 137 cm, as being static background. **Figure 3** shows the relative frequency of different considered static environment echoes for each sensor of an ultrasonic ring. The figure shows that for some directions the static environment echoes are always the same, whereas for some directions they vary quite a bit.

3.3 Localization

After the determination of the echoes caused by the environment the system can start the localization of a person. The radio telemetry module that is connected to the I^2C bus simultaneously triggers all sensors on the ring to send an ultrasonic pulse and then collects the detected echoes. After the localization software has received these echoes, the telemetry module triggers the sensors again. Currently, this cycle, which consists

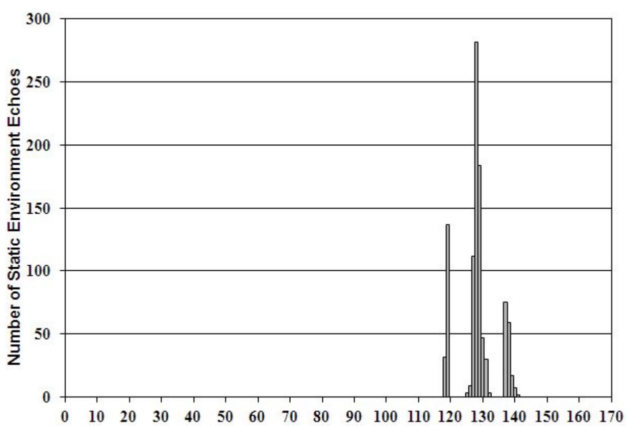
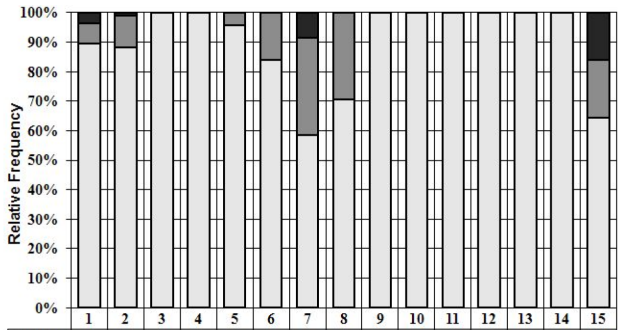


Fig. 2. Histogram of echoes caused by the static environment for one sensor. In this case, the system regards the echoes 119 cm, 128 cm and 137 cm as static environment echoes.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Echo 3	4	1	0	0	0	0	9	0	0	0	0	0	0	0	16
Echo 2	7	11	0	0	4	16	33	29	0	0	0	0	0	0	20
Echo 1	89	88	100	100	96	84	58	71	100	100	100	100	100	100	64

Fig. 3. Relative frequency of different considered static environment echoes for each sensor of an ultrasonic ring

of triggering the sensors, collecting the echoes and transmitting all values to the localization software, takes 200 ms.

After receiving the detected echoes the localization soft-ware determines the echoes that are caused by a person. Each echo value that is close to a value indicating static environment is regarded as a static environment one. Of the remaining echoes, values larger than the values for static environment are also for plausibility reasons – the sensor cannot "see" a person located behind the environment surface producing the first static echo. The next step is to determine a subset of these "qualified" echoes that is used to compute the position. For the purpose of this algorithm, the sensors of an ultrasonic ring are numbered 1 through 15 as shown in **Figure 4**. Sensors of the inner circle have even numbers, whereas sensors of the outer circle have odd numbers. Sensor 15 is the sensor with main propagation direction parallel to the normal of the ring plane.

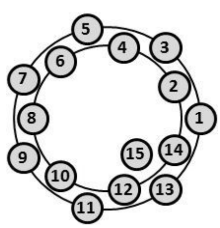


Fig. 4. Ultrasonic ring with ultrasonic sensors numbered 1 through 15 (top view)

First, the algorithm checks whether the person is located beneath the ultrasonic ring. In this case, the sensor with number 15 as well as the sensors of the inner circle will have detected echoes caused by a person. Therefore, the subset for computation contains the echoes of these eight sensors. However, if the sensors of the inner and outer circle have measured echoes caused by the static environment and only the sensor with number 15 has noticed an echo caused by a person, the subset merely contains this single echo.

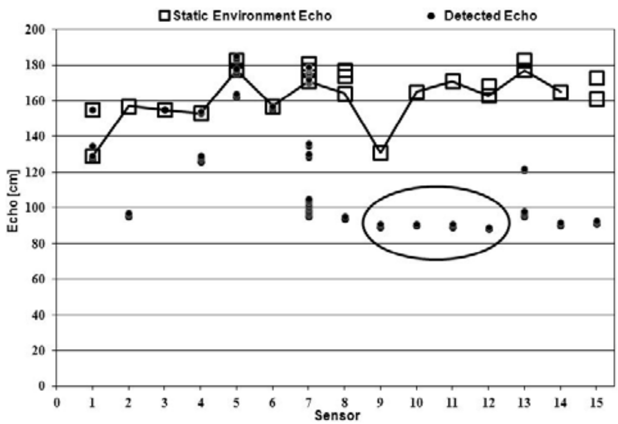


Fig. 5. Static environment echoes and detected echoes caused by a person at position 9 in Figure 7. The shortest static environment echoes of the sensors of the inner and outer circle are connected by a line. The echoes of sensors 9 to 12 (ellipse) are used to compute the person's position.

Otherwise, if these two cases do not apply, the algorithm computes groups ("windows") of four directly adjacent sensors, except for the sensor with number 15. Each group is comprised of two sensors of the inner circle and two sensors of the outer circle. Hence, there are 14 groups with sensors ({1,2,3,4}, {2,3,4,5}, … , {14,1,2,3}). Then, the algorithm calculates for each group the number of sensors that have detected a qualified echo, i.e. an echo caused by a person, and also computes the average echo of these up to four qualified echoes. After that, the group with the maximum number of qualified echoes is chosen as the subset for computation. If there is more than one group with the maximum number of qualified echoes, the group with the shortest average echo is selected. **Figure 5** shows the static environment echoes and the detected echoes caused by a person at position 9 in Figure 7. There are some groups with the maximum number of qualified echoes. Therefore, the algorithm takes the average echo into account and selects the qualified echoes of group {9,10,11,12} as the subset for computation.

After determination of the subset with qualified echoes to be considered, the spatial position in the local coordinate system of the ultrasonic ring (the origin is the ring center) is calculated for each of these echoes. For this purpose, the system computes both the position vector and the direction vector for the main propagation direction for each affected ultrasonic sensor. The length of the direction vector is set to the measured distance of the corresponding echo. Then the spatial position can be computed by adding the associated position vector and the associated direction vector.

After determination of the spatial positions, the system calculates the centroid $\vec{p}_c$ of these positions:

$$\vec{p}_c = \begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} = \frac{1}{n}\sum_{i=1}^{n} \vec{p}_i = \frac{1}{n}\sum_{i=1}^{n} \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix}$$

where n is the number of spatial positions and $\vec{p}_i$ is the position vector of the i[th] spatial position. **Figure 6** shows an example by using four echoes to compute the centroid (position 1 in Figure 6). Afterwards, the dimensions of a person are taken into account. Therefore, the algorithm examines the distance d_c in the xy-plane between the ring center and the computed centroid:

$$d_c = \left| \begin{pmatrix} x_c \\ y_c \\ 0 \end{pmatrix} \right| = \sqrt{x_c^2 + y_c^2}$$

If the distance d_c is less than 20 cm, both the x-value and the y-value of the centroid are doubled. Otherwise, the distance is increased by 20 cm in the xy-plane:

$$\vec{p}_r = \begin{pmatrix} x_r \\ y_r \\ z_r \end{pmatrix} = \begin{cases} \begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} + \begin{pmatrix} x_c \\ y_c \\ 0 \end{pmatrix} & d_c < 20 \\ \begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} + \frac{20}{d_c} \cdot \begin{pmatrix} x_c \\ y_c \\ 0 \end{pmatrix} & d_c \geq 20 \end{cases}$$

In the example in Figure 6 the consideration of person's dimensions shifts the previously computed position 1 ($\vec{p}_c$) to the final position 2 ($\vec{p}_r$). The recalculated position $\vec{p}_r$ is then transformed from the coordinate system of the ultrasonic ring into the coordinate system of the room. The resulting position is the assumed position of the person.

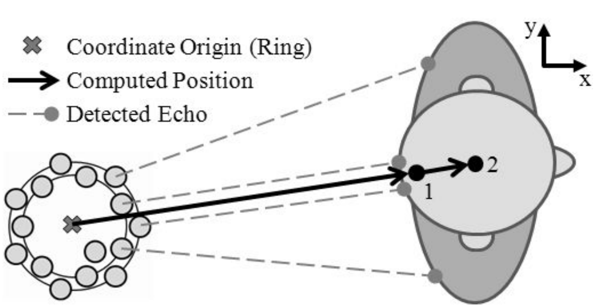


Fig. 6. The algorithm uses four echoes caused by a person to calculate the centroid (1) of the corresponding spatial positions. Considering the dimensions of a person, the algorithm computes the final position of the person (2).

4 Evaluation

For the preliminary evaluation the system was installed in the bedroom of the IDEAAL living lab in Oldenburg, Germany. The main objective was to determine the accuracy of the system. In order to achieve this, 14 different positions inside the bedroom were defined, as shown in **Figure 7**. Each position was numbered and marked either on the floor or on the bed (position 7) and chair (position 8) respectively.

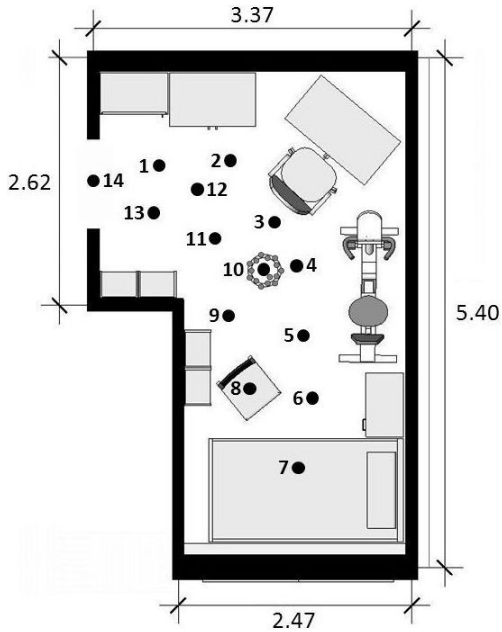


Fig. 7. The bedroom of the living lab, where the experiment took place. The ultrasonic ring is in the middle of the room. The positions of the experiment are numbered from 1 to 14.

Within the experiment a person walked along the path that was defined by the numbered positions. When the person had reached a position, he remained at this position for 30 seconds and then walked to the next one. This evaluation also took different body positions into account. At position 7 the person lay in bed, whereas he sat on the chair at position 8. In the other cases, the person stood at the marked position.

During the whole period of this experiment, the localization software analyzed the echoes detected by the ultrasonic ring mounted on the ceiling of the bedroom. Based on these analyzed echoes, the positions were computed and then stored in a database for further analysis. After completion of this experiment, the differences between the computed positions and the corresponding real positions were determined. Average, minimum, maximum and standard deviation of these differences for each position are shown in **Figure 8**.

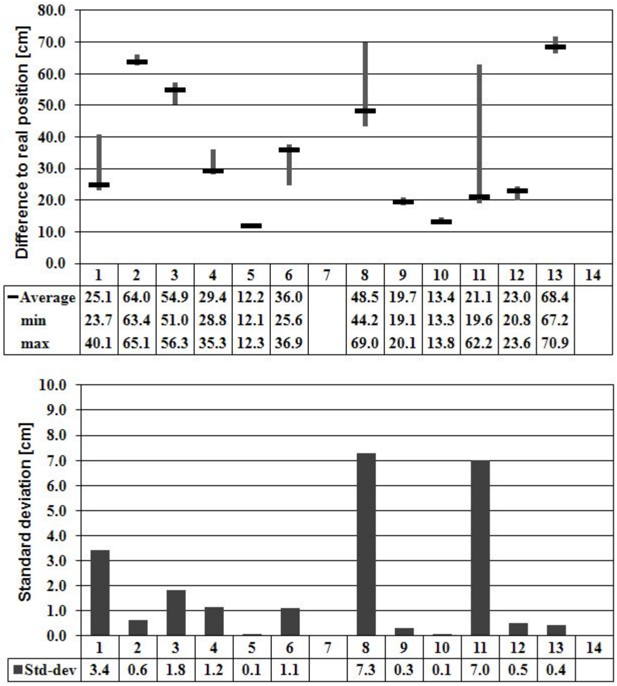


Fig. 8. Results of the conducted experiment for each tested position. The diagrams show the average, minimum, maximum and standard deviation of the differences between the computed and the real positions. At positions 7 and 14 the system could not localize the person.

In many cases, if the system was able to compute a position, the average difference is less than 50 cm. However, sometimes the average difference is greater than 50 cm. This may occur when multiple reflections influence the detected echoes or when the sensors on the left (right) side of the person only detect echoes caused by the static environment, whereas the sensors on the other side detect echoes caused by the person. In the latter case, the ascertained distance to the ring center is suitable, but due to the missing echoes on one side of the person the computed position is displaced in the direction of the other side. Because of the distance between the ultrasonic ring and the bed, only echoes caused by the static environment were detected at position 7. In addition, the problem at position 14 was that the person stood in the doorway and the system was not able to distinguish between echoes caused by this person and echoes caused by the door frame. Considering only positions where the system was able to compute a position, the average difference between the computed and the real positions is 34.6 cm (standard deviation is 19.6 cm).

5 Conclusion and Outlook

Our current approach to localize a person inside his or her domestic environment was presented. The approach uses ultrasonic rings mounted on the ceiling of the environment. 15 ultrasonic sensors are placed at each ring. In order to compute the desired position the first detected echoes of these sensors are analyzed. The first step is to distinguish between the irrelevant echoes caused by the static environment and the "interesting" echoes caused by a person. The sensors of one ultrasonic ring are triggered simultaneously every 200 ms. However, this simultaneous triggering can induce problems with echoes whose corresponding ultrasonic pulses were sent by one sensor, but collected by another sensor. These problems do not occur if sensors are triggered sequentially. However, this is not suitable for tracking a person because the cycle, which consists of triggering all sensors of one ring, collecting the echoes and sending them to the localization software, would then take 3500 ms, whereas the simultaneous version only requires 200 ms. In order to minimize the influence of negative effects caused by triggering the sensors simultaneously, the second step is to determine a subset of these interesting echoes whose included echoes seem to be more suitable than the other ones. Afterwards, a spatial position for each echo in this subset is calculated. Then the centroid of these spatial positions is determined, which is the preliminary position of the person. The next step takes the dimensions of a person into account. After this, the resulting position is transformed into the room coordinate system. The outcome is then the computed location of the person.

Nevertheless, the system currently has some limitations. One limitation occurs when the person sits on a chair and the chair is within the coverage of an ultrasonic ring but the distance between the ring and the chair is too large. In this case the system is not capable of localizing the person because it cannot distinguish between the echoes caused by the chair and echoes caused by the person. This limitation requires a suitable positioning of one or more ultra-sonic rings in one room.

Furthermore, at present the system does not utilize "historic" information about previously computed positions. This information would most probably help improving the computation of a person's position, because the possible distance between two localizations 200 ms apart in time can only be rather limited (up to 30 cm [9]) at walking speed. Therefore, we plan the consideration of previous positions to support the selection of the interesting echoes used to determine the position. Additionally, the system has problems with changes in the static environment, for example after opening/closing a door or window as well as after moving of furniture like chairs. This issue can also be addressed by taking previous computed positions into account to update the set of echoes caused by the static environment. Finally, the system is incapable of localizing more than one person at the same time. Therefore, the system should be deactivated while there is more than one person inside the domestic environment. This is only a minor limitation because the system only focuses on use cases, such as mobility assessments and activity recognition, which are designed to capture and analyze sensor data during the presence of a single person.

Despite the current limitations we think that the presented approach has a high potential for a tag-free and unobtrusive indoor localization with sufficient accuracy for AAL, in particular if previously computed positions are taken into account. We also expect that a large-scale production would provide a cost-effective solution for indoor localization.

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Unobtrusive Fall Detection Using 3D Images of a Gaming Console: Concept and First Results

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Abstract. Image based fall detection is costly and rated obtrusive by those being monitored. The approach presented in this paper uses a cost efficient gaming console for 3D image generation. The image itself covers a range of about up to 30cm above the floor and allows for a nearly invisible positioning e.g. under the bed. Image analysis allows classifying events like "feet in front of the bed", "fall", "leaving the room" and "activity in the room". For use in nursing homes and in home environments a system design has been implemented which is compatible with the guidelines of the Continua Health Alliance and fulfils data privacy requirements. The system supports the nursing home in its obligations for documentation of events. It was successfully tested in a laboratory environment and in a small scale test using three rooms of a nursing home in order to prepare for a large scale trial.

Keywords: Fall detection, 3D image analysis, fall prevention, standards, Personal Health, AAL.

1 Introduction

Fall prevention and detection is of key relevance both for the persons suffering from the fall and for the carers, be those family members or professionals. Falls have a 30% likelihood per year for persons above 65 [1] and cause to serious injuries (e.g. fracture of the hip, shoulder or the upper arm). In addition, they have high impact on activities of daily living (e.g. hospital stays, capacity to live alone, need to move to a nursing home). However, not only the persons themselves, but professional carers face claim and liability requests from the health and nursing insurance.

While fall prevention based on an inspection of the living conditions (e.g. door sill, carpet edge, lighting) can be achieved by eliminating this potential obstructions, preventing a fall of a person by continuously analysing the person's behaviour is much more demanding. Most of the sensors and systems developed are able to detect a fall which has taken place, only some methods like camera based ones may correctly identify the situation prior to a fall. In some instances the person itself has to initiate an alarm even though the person might not be capable to do so. Table 1 presents an overview to fall detection approaches.

Table 1. Sensor principles used for fall detection

Measurement variable	location for sensor	fall prevention	fall detection
acceleration [2]	body worn	-	x
orientation [3]	body worn	(x)	(x)
inertial force [4]	body worn	(x)	(x)
atmospheric pressure [5]	body worn	-	x
alert button	body worn	-	(x)
pressure mat [6]	ground floor	-	x
proximity sensors [7,8]	ground floor	-	x
motion detector (infrared, ultrasound, radar)	ground floor	-	x
camera(s) [9,10]	room	x	x

Some systems use a combination of measurement variables for better detection of situations. Despite the advantages of camera based systems (e.g. support of fall prevention, documentation of the situation "fall" for avoiding claims) they suffer from user's perception of being under surveillance all the time due to the typical visibility of the camera and potentially breaking of privacy. In addition camera based systems are rated to be difficult to install, to require sophisticated illumination of the scene, to demand significant computational power for image processing and thus to be rather expensive.

Despite these facts, this paper presents an unobtrusive camera based approach using 3D images provided by a gaming console and processed by a simple barebone PC. Overall this sensor design is inexpensive and has been embedded in an overall system architecture which mainly relies on standards and profiles for "Personal Health Monitoring" developed by organisations like ISO/IEEE, HL7, Integrating the Healthcare Enterprise (IHE) and Continua Health Alliance (CHA).

2 Material and Methods

This chapter addresses two key aspects: (i) image analysis and (ii) the overall system design and integration.

2.1 3D Image Acquisition and Analysis

3D image acquisition based on time-of-flight uses time delays measured for short light impulses to determine the depth as the third dimension. It is an established approach which however it is characterized by low image resolution and high costs.

Alternatively the method stereo vision relies on two images taken from two viewpoints and calculates the depth from the geometric distortion between the two images. Besides computational demands it requires proper lighting of the scene for successful operation. Stereo triangulation as a special form of stereo vision projects a point matrix using infrared light. Deriving the depth information is based on triangulation between the known point matrix (reference image) and the recorded image from the scene [11].

This method is implemented by gaming consoles for monitoring user interaction and control. As such, the Microsoft product "XBOX 360 Kinect Sensor (Kinect)" [12] provides a versatile approach for 3D image acquisition for fall detection at acceptable costs. It has a high resolution of 640 x 480 pixels at a rate of up to 30 images/s and by using an infrared point matrix it operates independent of lighting even at night. It is enhanced by an optical camera and a directional microphone. For interfacing, a SDK is provided by Microsoft [13].

To achieve unobtrusiveness to a large extent, the Kinect is positioned at 30cm height above the floor. In contrast to ceiling based mounting [14, 15] it is barely visible when positioned e.g. underneath a bed. At this height is does not violate the persons privacy due to the limited view but this positioning put requirements on the algorithms for fall detection. In addition, a typical analysis of the optical flow for each pixel within a sequence of images for fall detection will not be possible.

Key objective for development is the correct classification of events like fall. Furthermore, the image analysis should be achievable without significant computational resources as provided by a netbook or barebone system. Images analysis is accomplished in five steps.

2.1.1 Image Acquisition

The Kinect is connected with USB to the analysis system. The image repetition rate is limited either by the Kinect to 30 images/s or by the computational power of the analysis system.

2.1.2 Image Preprocessing

Images are checked for consistency, e.g. pixels with an unrealistic depth compared to the size of the room or their direct neighbourhood are discarded.

2.1.3 Segmentation

Segmentation should result in regions identifying e.g. a person after a fall or feet on the floor. Different approaches have been assessed:

1. Representing depth information by colour coding the continuous comparison between a reference image and the actual image reveals changes. However, moving a chair and thus requiring an update of the reference image cannot be taken account of.

2. Using a filter (Gaussian) on the difference image allows differentiating between small and large changes. Small changes result in an update of the reference image, whereas large ones indicate an event like a fall.
3. Octtrees is a true 3D data representation which divides a volume into halves, as long as the pixels exhibit different values in that volume [16]. The octtree approach was motivated by trying to reduce the computational requirement.

Overall, the approaches (1 to 3) were not sufficient, either due to not allowing for updates of the reference image (1) or having high computational requirements (2 and 3). Finally, a manual pre-segmentation of the reference image was performed to identify areas allowing a fall and those not being relevant (e.g. a cupboard). As a result, the analysis executes faster, however at the extent that the pre-segmentation has to be done again once the Kinect is repositioned in the room.

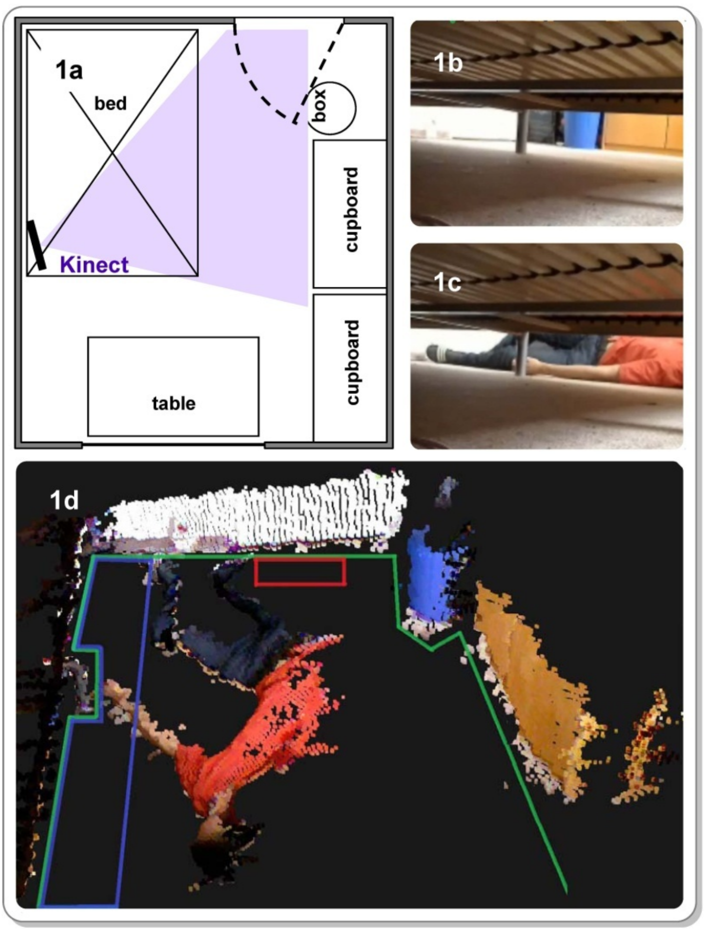

Fig. 1. System setup in the room, layout (1a), view without person (1b), view with person (1c) and delineation of areas (1d)

Figure 1 presents the approach chosen with 1a depicting the layout of the room and the position of the Kinect. The views in 1b and 1c show the situation without and with a person after a fall. Finally, for illustrating the pre-segmentation a higher viewpoint has been taken in 1d and areas have been outlined (floor in green, door in red, area in front of the bed in blue).

2.1.4 Feature Extraction

Feature extraction is a prerequisite for object detection and later on classification of situations. In a first step the object's height and width are determined from the 3D data to exclude too small or too large objects not truly representing a person. Compactness, the ratio of circumference to area, allows excluding ball- or cubic-like objects not representing persons. For the objects remaining their surface is divided into patches and their orientation is analysed. A parallel orientation of multiple patches to the floor is rated to originate of a non-human object, e.g. a wheelchairs and leads to the exclusion of this object. The view on a person after a fall may be obstructed by another object. To compensate for this effect, the longer axis of objects is used in a regression analysis to reassemble the object, provided that the change of slopes is less than a predefined limit.

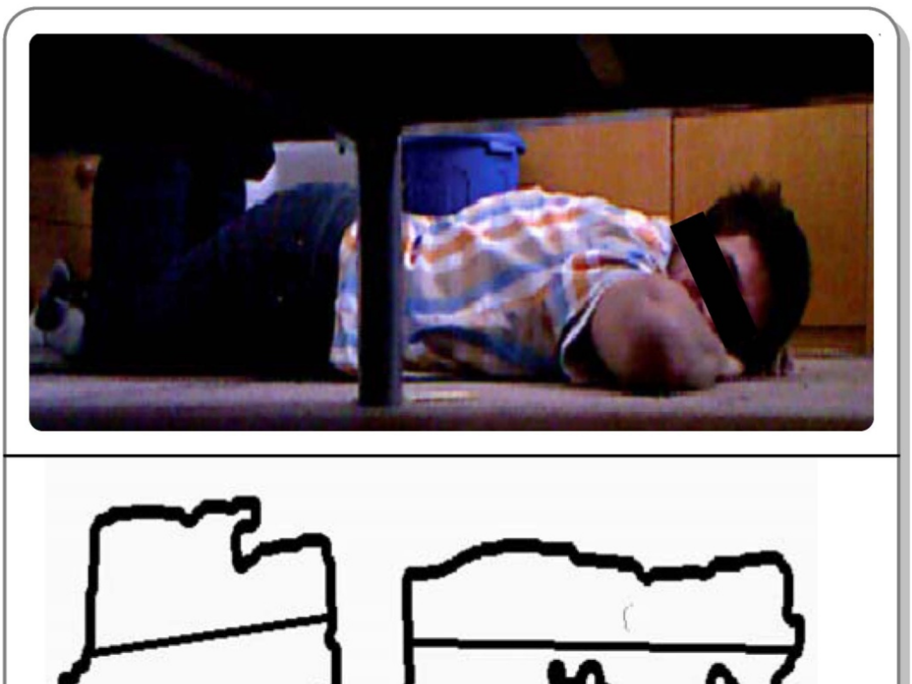

Fig. 2. Reconnecting separated objects

Figure 2 shows the image of a person being separated in two objects by the support pillar of a bed together with the objects outline and the calculated regression lines. Finally, for each object the centre of gravity is calculated. Since for persons the centre of gravity is located inside the object other objects like chairs can be excluded. For subsequent classification the object's location with regard to the areas of pre-segmentation is determined.

2.1.5 Classification

Classification of situations is performed with a decision tree. Figure 3 presents the weights for the situation "feet in front of the bed" which have been heuristically determined and adapted based on trials.

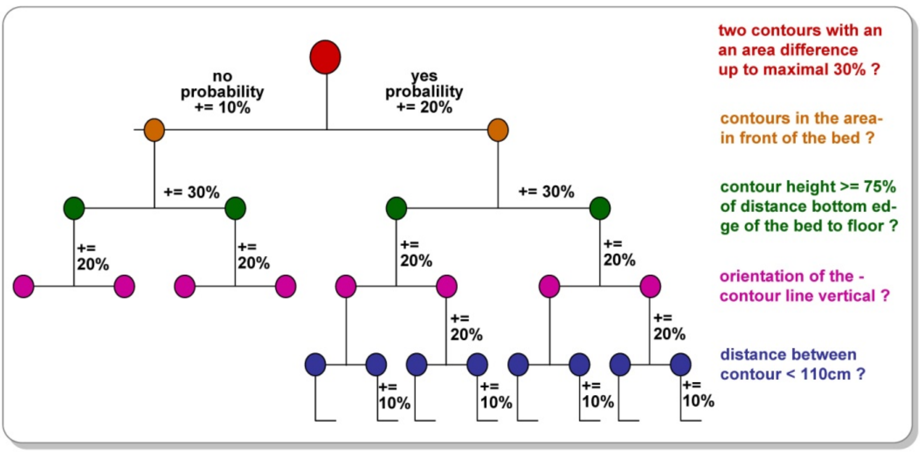

Fig. 3. Decision tree

2.2 System Design and Integration

System design requires analysing the current situation and requirements of a nursing home.

2.2.1 Analysis

Analysing the procedures in a nursing home for managing a fall situation revealed that besides the caring for the person who suffered from the fall, considerable effort is required for documentation. On the one hand, the fall has to be recorded for the person individually and on the other hand the fall and its implications lead to an update of the fall statistics of the nursing home, which has to be accomplished on a yearly basis. Furthermore, health insurances usually request further documentation to justify payment resulting in additional work for those involved. With an incidence of roughly two falls per person per year in a nursing home there is a requirement to support documentation. The system developed is able to assist by providing a sequence of events including images covering a limited time prior to the fall up to the actions taken after an alarm has been issued. This information has to be protected against unauthorized use and should only be available to the management of the nursing home.

Extending the analysis to the technical infrastructure of a nursing home reveals a large variety. Only few nursing homes can provide a Wi-Fi infrastructure, in most of them phones are the only communication means available. For alarms most nursing homes are equipped with a separate nurse alarm system, which might be interfaced with the telephone system or just provide acoustical or optical alarms for the nurses.

2.2.2 Components

Both the Kinect and the analysis system based on a netbook or a barebone are located in the room of the person under surveillance. This setup prevents image information leaving the room to guarantee privacy. Only in case of a detected event, image data may be transferred to a server for documentation purposes. The server acts as a central unit for all rooms and has to monitor and manage events as well as system availability. Since image analysis is performed in the room the scalability requirements of the server are not demanding. Reviewing this setup it appears to be comparable to Personal Health Monitoring (PHM) architectures, which are well specified using standards and profiles.

2.2.3 Personal Health Monitoring Designs

The Continua Health Allicance (CHA) issues guidelines to allow for interoperability for PHM using international standards (e.g. from HL7, ISO, IEEE) together with profiles (e.g. from IHE) [17].

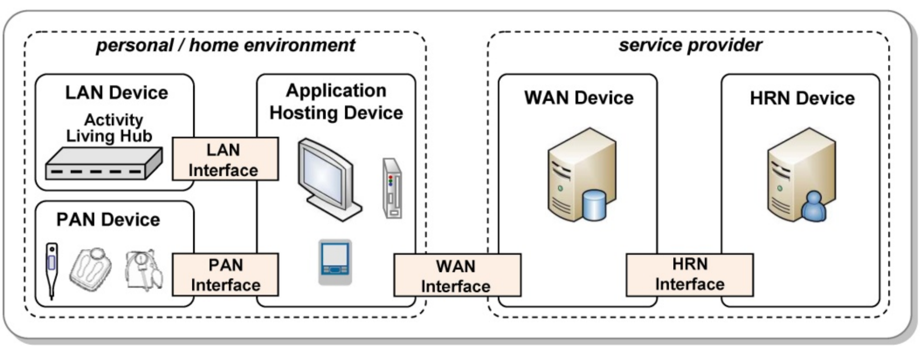

Fig. 4. Continua Health Allicance reference architecture

Figure 4 shows the reference architecture which provides vital sign monitoring as well as an activity living hub for interfacing with systems for situation analysis and smart home devices. The ISO/IEEE 11073 provides domain information models to support plug & play for vital sign data. Data aggregation is performed by the application hosting device within the personal environment. Service providers receive the information as HL7 messages via the WAN interface and use the HRN interface to store it in a health record based on the External Document Sharing (XDS) profiles of IHE.

2.2.4 Fall Detection System Design in the Context of the CHA Reference Architecture

There are at least two approaches feasible based on the CHA guidelines:

1. The ISO/IEEE 11073 Activity Living Hub features the binary signal "fall", but does not allow for some kind of qualification e.g. with regard to the certainty or identification of the situation "feet in front of the bed".
4. In extension of the vital sign models of the ISO/IEEE a new domain model for the situation "fall" could be designed and provide context and qualifying parameters.

Both approaches require the implementation of the Application Hosting Device (AHD), which as a generic solution allows for inclusion of other vital signs. Considering development resources and time an alternative approach has been taken. The image analysis system as a component is extended to include the AHD functionality, however without providing a physically implemented PAN interface but using a newly designed domain model for the situation "fall". System interaction for the nurses is available from the WAN device which is located in the ward's office respectively. Finally, the HRN device serves for documentation purposes.

2.2.5 System Architecture

Figure 5 shows the complete system architecture which matches the need for further interfaces. On the one hand the image / video documentation associated with an alarm requires a separate channel, since the ISO/IEEE does not allow for this type of data and the resulting data rates. On the other hand, there is a need for interfacing with the infrastructure of the nursing home for forwarding alarms. A low level approach is the use of a GSM modul compared to integration with the nurses' intercom alarm system.

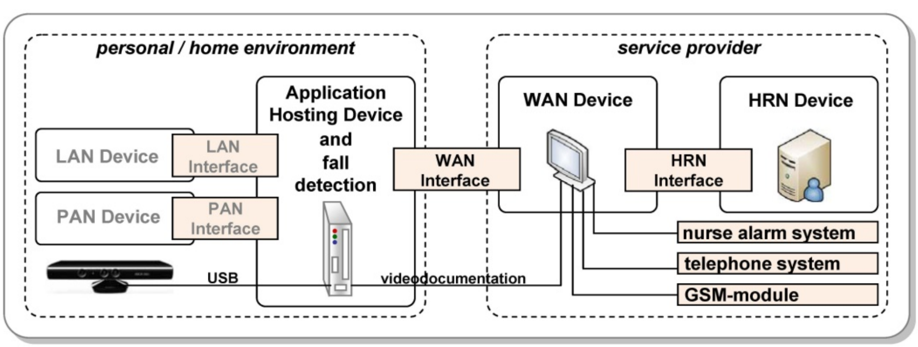

Fig. 5. System architecture

2.2.6 Implementation

Implementation followed the previously described system architecture. Despite the fact, that Microsoft provides an SDK for the Kinect, a different driver from the OpenNI initiative [18] has been selected to allow for Unix and Windows based operating systems. Further assessment showed, that this driver requires less resources compared to the SDK. The image analysis platform uses a Unix operating System (Ubuntu [19]) and C++/C for the image analysis algorithms. The AHD and WAN device are implemented with the open source .Net development environment mono [20] to allow applications and web services based on C#.

3 Results

Even though the implementation does not include the PAN and LAN interfaces the system design is according to the CHA guidelines. A domain information model for the situation “fall” has been developed and data and events are transmitted using HL7 PCD-01 messages within web-services. Data and events are recorded and get continuously evaluated to generate alarms, document the resulting actions and provide protocols based on the Clinical Document Architecture (CDA). Alarms are forwarded to an Asterisk Server [21] which acts as a telephone system for sending alarms to either IP-based phones or mobile phones via the GSM module. Each recorded event is preceded by the last 30 seconds prior to the event. Related image data can be received from the analysis system and kept on the server. Access to this data is controlled by a hierarchical access management which discriminates between nurses, ward responsible nurses, nursing home management, and administrators. Communication uses encrypted channels and no patient identifying information is available in the personal environment. Mapping of data to a specific person is done in the WAN device based on the prerequisite, that device IDs have to be assigned to a person upon installation.

The fall detection device has been evaluated extensively in a laboratory setting with the objective of a correct classification of situations. For improving the expressiveness of the tests six persons with different weight and height have simulated a fall within various room setups. The situation “activity in the room” was easily classified without any error. “Leaving the room” could be detected in 17 (85%) out of n=20 cases as well as “leaving the bed” with 88% (n=71). The situation “fall” was correctly classified with 93% (n=55).

Currently the system is evaluated in a real setting in a nursing home for three patients. Communication between the analysis stations and the central server has been established using Wi-Fi and an IP-based telephone provides alarms to the nurse on duty. This real-life validation will improve the applications in order to prepare for a larger validation with more than one nursing home.

4 Discussion

Taking the reference architecture of the CHA as a starting point for system design and integration allows for interoperability and extensibility. However, some technical and organisational requirements could not be realized:

- The specification of the ISO/IEEE 11073 activity living hub includes a fall signal, but fails to represent context information associated with a fall. The development of a domain information model for the situation fall compensates for this deficiency, but is not fully compliant to the scope of vital sign data as conceived by the ISO/IEEE. Furthermore, a separate communication had to be established separately from the ISO/IEEE WAN interface for transmitting images to amend the documentation of events and assist in liability issues.
- Successful fall detection results in events and alarms, which have to be communicated reliable starting from the sensor up to the health record repository. This implies means to check for availability at regular intervals a feature, which has not yet been addressed by the CHA guidelines. In particular, relying on PCD-01 type of messages is a mainly unidirectional communication inhibiting regular availability checks. A possible solution to recommend to CHA would be to consider the Alarm Communication Profile of IHE [22] which has been developed for use in intensive care settings.
- In contrast to the CHA guidelines there is no personalisation done at the level of the application hosting device (AHD) in the personal environment. This approach is justified since the AHD has no user interface and its task is mainly to map the instance of domain information model to the PCD-01 message at the WAN interface. As such, some of the mandatory fields in the PID segment in the PCD-01 message can not populated appropriately.

The Kinect has proven to be suitable for fall detection as well as the unobtrusive positioning at a low distance above the floor. This approach undoubtedly leads to better acceptance by the users. As a gaming console the costs for the Kinect are low and thus support to transfer this fall detection system to a home setting as well. In this case the WAN interface would connect to a detached service centre using a standard internet connection.

5 Summary

The validation done so far confirms the 3D image based approach and the system design. Different situations could be identified successfully including the situation "feet in front of the bed" which might indicate a subsequent fall depending on the person's health state. The complete documentation of events supports the nursing homes in their reporting duties and assists in liability issues raised by payers and insurers. The implementation follows international standards and guidelines, thereby facilitating integration and interoperability with other systems. It is expected, that the ongoing trial in a nursing home will be successful with results to be presented at the conference and to leverage a larger scale trial in more than one nursing home.

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Part IV:
Evaluation, User Acceptance and Usability

Rule-Based Approach for Simulating Age-Related Usability Problems

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Abstract. *Ambient Assisted Living* requires easy to use interfaces, making *usability* a critical feature. Because usability evaluations are resource and time consuming, several automation efforts have been made, one of which is the simulation of users interacting with UIs. In this article, we present ongoing work of a tool for automated usability simulations that allows simulating age-related deficits. The tool is specifically intended to be used by IT practitioners, i.e. in difference to cognitive architectures that allow similar simulations, this tool does not require extensive knowledge in cognitive science. A core component of the simulation tool is its rule-based *User Model (UM)*. During a simulated interaction, the UM selects actions causing a model of the UI to change states until a specified task goal is satisfied or the UM "gives up". Interactions of the UM are calculated from probabilities which are informed by rules drawing on user and UI attributes. Using a Monte Carlo approach, the simulation is iterated, resulting in a set of task solutions where non-optimal solutions may indicate usability problems. By analyzing which rules led the UM to interact non-optimally, our approach can offer hints on how to improve the UI. While our approach cannot render user-based evaluations unnecessary, our aim is to substantially reduce the effort involved in usability testing of UIs as well as to provide an automated tool that can be used early on in the development process.

1 Introduction

Ambient Assisted Living (AAL) solutions are often highly distributed and aim at integration into the "natural" environment of their users. As a result, they exhibit a wide variety of *User Interfaces (UI),* e.g. showing information on video screens and ambient displays, or providing control through touch displays and *Speech Dialogue Systems (SDS)*. Easy to use UIs are a central aspect for AAL solutions which makes *usability* a critical feature. But conducting usability evaluations is a time and resource consuming process. This is especially true, if the system under evaluation is aimed to be used by elderly people as in the case of the majority of AAL systems. Not only is the group of elderly users more diverse than younger users – showing significant differences in their sensory, motor and cognitive abilities as well as in their knowledge and attitudes towards technology – but due to their deficits, lifestyles, and motivations they are also harder to recruit for usability tests (see e.g. [7, 13, 22]).

One way to reduce both costs and effort for evaluations is automated usability testing by model-based evaluations that use simulations [14]. This article describes ongoing work of a rule-based *User Model (UM)* for simulating user interactions that are affected by deficits e.g. *impaired vision* – and general age-related characteristics (e.g. *vision, hearing, tremor, affinity for technology, computer anxiety, domain expertise, cognitive skill*; see [9] for a detailed list) – which can bear significant impact on interactions with UIs. An implementation of our UM is used in the MeMo workbench [8], which is a prototype for rule-based simulations of user interactions for conducting automated usability evaluations. The areas of application include evaluation of classic window-based UIs[1] , web-based UIs and voice-based UIs[2]. By these means, the approach is also intended to be generally feasible to model the use of different interaction devices. Moreover, the workbench is aimed to enable usage by practitioners that are involved in the creation of UIs. Therefore, controlling simulations for (age-related) impairments is intended to be mostly intuitive (e.g. by specifying *"the user has good/bad visual perception"*) and does not require the practitioner to have expert knowledge in cognitive science. Our UM is designed to be as task-independent as possible in order to reduce the cost and effort for its application: to find usability problems in different UIs and with different tasks. Similarly, our model is intended to facilitate the analysis of simulations, e.g. finding user-specific usability issues or even provide critique [14], i.e. give suggestions for improving the UI by highlighting interaction problems.

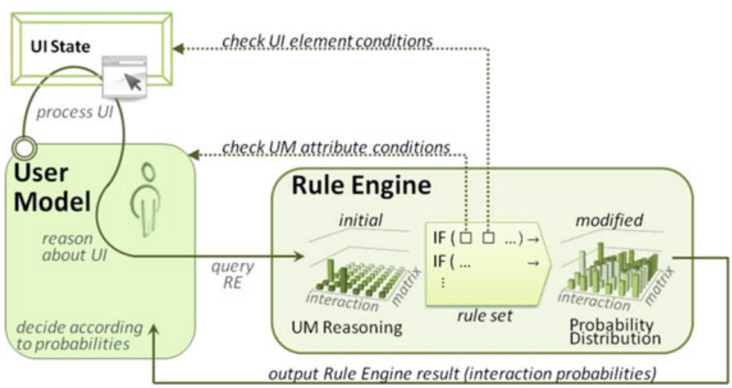

Fig. 1. The general process for employing the rule engine during interaction simulations: The rule engine manipulates the probabilities for potential UM interactions. The UM decides its next step probabilistically according to the distribution. Note that conceptually, the *rule set* is a component of the UM, since the caused probability manipulations are an integral part of the UM's decision making process.

[1] Windows, Icons, Menus, and Pointing devices (WIMP).
[2] Speech Dialog Systems (SDS).

Rule-based usability simulations in MeMo follow a Monte Carlo approach: repeatedly, user interaction is simulated with a given goal of solving a defined user task. Each single iteration of this interaction simulation starts in a specified state of the UI and continues until the task is solved or the UM "gives up". Until then, in each step, probability distributions are calculated in order to decide the next action of the UM and thus causing the UI model to change to the next state. The probability distributions are calculated using a set of rules, in which for example, a rule concerning the *Graphical UI (GUI)* may state that "if button X has a high contrast, then increase its probability-to-be-used". Rules are specified with the help of an *Extensible Markup Language (XML)* syntax, which allows the set of rules to be easily extended and modified.

The simulation results give multiple task-solutions which potentially reveal a broader spectrum of usability problems as compared to a single task-solution, e.g. expert interaction. In addition, the frequency of specific task-solutions is a further indicator for their importance. Finally, by analyzing the applied rules in each iteration step, semantically relevant reasons for the UM's choice can be provided. This allows deriving hints on how to improve the UI.

In [15] former work on the MeMo workbench is described based on a correct solution path for specified user tasks, which had to be provided by the practitioner. In this approach, errors are simulated by automatically introducing deviations from the correct solution path and error corrections are simulated by returning to this correct path. This strategy of producing usability problems shares similarities with approaches described in [20] and [17]. However, it is limited in that only foreseen error types at certain key points in the task solution can be simulated. In difference, the current approach described in this article, computes correct solution paths automatically but only uses them as post hoc measure for the correctness (i.e. determining deviations) and the successful completion of simulated solutions (i.e. reaching the goal condition).

The current concept and architecture of the MeMo workbench were introduced in [8] including a brief description of the rule mechanism and giving a short summary for using the workbench to replicate an experiment in which a SDS was tested. The set of rules was derived from user experiments and literature research. The article [9] describes the modeling of a SDS using the workbench. With addition of a statistical model, experimental data is replicated in simulations. The article also features a short high-level description for the rule mechanism.

In the following article we discuss this rule mechanism of the MeMo Workbench in more detail. First, we will give a short summary of the simulation process (for a more detailed discussion we refer to [9]). Then we describe the rule mechanism illustrated by an example and followed by a discussion.

2 Related Work

Automated usability evaluation is usually carried out with computer-aided tools and models of the intended user and the system to be evaluated. In most approaches the evaluation process consists of a simulation of user interactions while performing specified tasks. With GOMS-based methods [16], evaluation results typically provide *execution time* predictions and *learning rates*. Cognitive architectures [25], e.g. ACT-R [2] and EPIC [18], allow creating more detailed and consistent models of human information processing, e.g. for uncovering *cognitive load*. However, these simulations are highly task dependent and the creation of models usually requires extensive knowledge in the domain of cognitive modeling.

CogTool [25] mitigates the effort involved in developing specialized ACT-R models. A model representation for the user interaction is derived from input sequences which a practitioner demonstrates on a mock-up of the UI. Then CogTool compiles and executes an ACT-R model for expert interaction, i.e. an ideal interaction path for the task is simulated. This primarily allows evaluating the efficiency (*"how long does it take?"*) for the demonstrated task solution. Deviations from the demonstrated interaction path are not considered. This is addressed by an extension to CogTool, the CogTool-explorer [27]. Building on the work of SNIF-ACT [11], CogTool-explorer implements a model for *information seeking behavior* that uses a label-following strategy [21] driven by semantic similarity measures.

Similarly, MeMo [8] addresses the simulation of exploratory user behavior, i.e. simulations of users finding different task-solutions. This allows investigating efficacy *("is it possible to fulfill the task?")* as well as efficiency *("how many steps are needed?")*. UI models are created by the practitioner, which may be based on real systems or early prototypes. MeMo also provides an import-feature for web pages which allows creating the required UI elements automatically, while the interaction logic needs to be added afterwards. Due to the nature of exploratory behavior, time prediction is not an integral feature of MeMo and thus other tools as, for example, CogTool, currently are more appropriate for predicting execution time of tasks.

In [3] a simulator is presented that aims specifically at the evaluation of *assistive* user interfaces by predicting likely interaction patterns for disabled and able-bodied users. The simulation is based on mappings between descriptions of the device space and "knowledge" from the specified user space, which both need to be supplied by the evaluator. Tool support for learning of "first time users" is provided by an interactive simulation process.

Similar to ACT-R, the UM of the programmable modeling approach described in [4], is based on SOAR production rules [19] and follows the assumption that human users interact rationally.

While the simulation of explorative behavior with cognitive architectures aims at highly verifiable models for user strategies, this also demands highly task-dependent models. In difference to these approaches, the work described here is intended to simulate explorative behavior with as little task-dependence as possible. As a result, the simulated user strategy may not match as precisely, but may only approximate the actual user strategy. In addition, parameters of our UM (e.g. for controlling deficits) are more abstract than that of most UMs in cognitive architectures and GOMS-based approaches. Yet, these differences to cognitive architectures allow for a broader area of application and, most of all, further the main goal of our approach: the specific application of uncovering usability problems in UIs by IT practitioners.

3 Rule-Based User Simulations

The next sections describe our approach for *interaction simulations*. First, we describe the interaction between UM and UI model and the concepts to achieve a goal driven interaction. Then, we elaborate on the role of *rules* in the simulation: how they are used to model variations in the simulation process based on characteristics of the *user*, *interaction history* and the *UI* under evaluation.

3.1 Simulation Process

The interaction process between user model and UI model is primarily driven by concepts of *speech act* theory [24]. Specifically, this means that interactions between both models are characterized by *information exchange,* i.e. information is exchanged in a question-answer structure by speech acts of *request* and *inform*. Accordingly, the user model initially requires user task knowledge for this information exchange, which needs to be specified by the practitioner in advance of each simulation. This user task knowledge consists of information particles for a successful accomplishment of the specific user task. Each information particle contains an attribute which specifies the domain of the information and a value which defines a specific assignment to that attribute, as for example the <attribute, value> pair: <*action*, *turn_on*>.

For exchanging user task knowledge, UI elements – e.g. buttons and text fields – are specified in the context of UI states as part of the UI model. These UI elements offer *input* and *output interactions,* e.g. the label of a button represents an *output interaction* and the click on that button is an *input interaction*. By means of these specific interactions, the user model is able to receive information from the UI model and to manipulate the UI model according to its own task knowledge. This procedure is similar to the concept of *label following* [21] which serves as a basis in similar approaches, e.g. [27]. As an illustration for such an interaction process, take a security guard who asks (*request*) for a name and password and letting someone enter only after validating the information that was provided (*inform*). A *login screen* of an application serves an equivalent function by *requesting* users to enter their name and password.

In the modeled interaction process, the UI facilitates the transfer of the requested information by providing necessary UI elements. Accordingly, the UM attempts to exchange user task knowledge with the UI model by employing input interactions which best fit the completion of the task goal in each UI state.

In order to realize this goal-oriented process, the UM enters a *reasoning phase* (see Fig. 1) during each step of the interaction process. In the reasoning phase the UI state's output and input interactions are processed, resulting in a selection of input interactions that the UM determines to further the *task completion*. Then the UM decides which action to take next, based on *probability distributions* (e.g. executing an *input interaction*, *"giving up"*, or *"asking for help"*). The decision is highly influenced by numerous dependencies between attributes of the UM and features of the UI model. These dependencies are handled by employing a rule engine in each interaction step. The rule engine *triggers* specific rules if their conditions are met.

The process of selecting input interactions is iterated until the task has been fulfilled or the UM "gives up", e.g. if the UM is not able to find relevant input interactions that correspond to the user task knowledge in the current UI state of the simulation.

In the next section we describe the structure of these rules and their effect on the interaction process in more detail.

3.2 Rule Definition

The *rule engine* calculates probability distributions that represent plausible behavioral choices of the simulated user. The basic idea is to capture typical behaviors of specific user groups in specific situations in a set of rule definitions. These rules are applied to the interaction process and modify the probability that the simulated user behaves one way or the other.

The rules follow a typical IF-THEN schema (see Listing 1): A single rule is defined by a description of a specific situation with regard to a specific user and a running system (*condition*) and a description of the typical reaction of the user when confronted with the situation (*consequence*). During simulation, the rule engine applies the rules according to their conditions (see Fig. 1). In this process, the UM queries the rule engine which then determines the probabilities to be modified – and also how they are modified – based on the current state: the rule engine checks the rule conditions against the current properties of UI elements and attributes of the UM and applies the probability modifications defined by the rules accordingly.

More specifically, in order to query the rule engine for the current simulation step, the UM provides initial probabilities for the interactions that are applicable in the current UI state (see Fig. 1). These initial probabilities may be, for instance, equally distributed for all interactions, or the UM may have increased the probabilities for some interactions that are considered to match the current task goal. We will not go into further detail about the initial probabilities, since they are part of the UM's reasoning process and not the rule mechanism (see e.g. [9, 26]).

After applying the rules, the rule engine returns a *probability distribution matrix* for all possible user interactions at the given system state of the UI model. This probability distribution is used by the UM to probabilistically select an interaction. Afterwards, the interaction is executed on the UI model and the simulation advances to the next simulation step.

In the remainder of this section, we will describe the structure and definition of rules in more detail. On an abstract level, we differentiate between three types of rules:

1. *Interaction rules* modify the *interaction probability distribution matrix* during simulations. These rules influence the interaction selection of the UM – most rules that are currently used in the MeMo workbench are interaction rules.
2. *History rules* are triggered by events – or sequences of events – during the simulation and are strictly speaking an extension of *interaction rules*. Here,

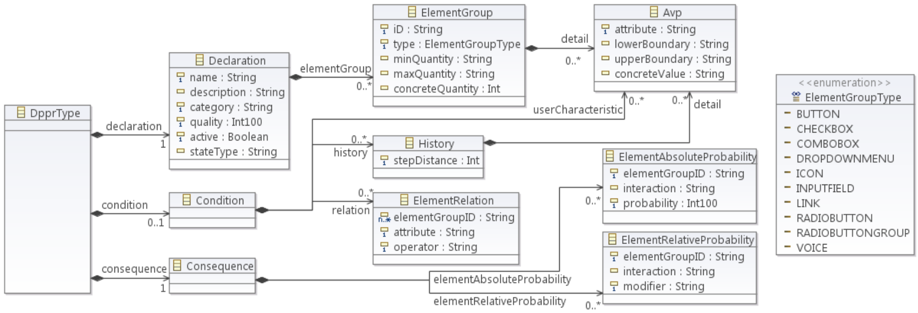

Fig. 2. Schema for XML rule definitions. *DpprType* is the main XML element that contains the rule's *Declaration* (required)*, Condition* (optional, see sect. 3.2), and *Consequence* (required) sections.

```
<?xml version="1.0" encoding="UTF-8"
      standalone="yes"?>
<dppr xmlns="de/dfki/rules/template">
  <declaration>
    <name>Button with low contrast to button
          background, small …
    </name>
    <description>Rule fires … </description>
[…]
    <elementGroup>
      <ID>ButtonGr</ID>
      <type>BUTTON</type>
      <concreteQuantity>1</concreteQuantity>
      <detail>
        <attribute>labelContrast</attribute>
        <concreteValue>low</concreteValue>
      </detail>
      <detail>
        <attribute>fontsize</attribute>
        <concreteValue>small</concreteValue>
      </detail>
    </elementGroup>
  </declaration>
  <condition>
    <userCharacteristic>
      <attribute>vision</attribute>
      <concreteValue>bad</concreteValue>
    </userCharacteristic>
  </condition>
  <consequence>
    <elementRelativeProbability>
      <elementGroupID>ButtonGr</elementGroupID>
      <modifier>---</modifier>
    </elementRelativeProbability>
  </consequence>
```

UI element conditions

User attribute condition

consequence

Listing 1. Example for a rule definition in XML format (for more details see Table 2) events refer to property values of previous UI states, so rules of this category modify probabilities depending on previous UI states of the simulation.

3. The third category of rules deals with the number of *information particles* that are selected by the UM for information transfer in the current simulation step. This type of rule is most relevant for SDS where more than one *information particle* can be transferred from user to system by a single *speech act* (i.e. "filling input slots of the SDS").

The structure of rule definitions is specified in an *XML Schema Document (XSD, see* Fig. 2). The top level structure divides a rule into three main sections, namely *declaration*, *condition* and *consequence.*

In the declaration part, general information about the rule is stated. It allows setting a name and a description for the rule. In addition, the relevant objects for the rule's application have to be declared: interaction widgets of a simulated UI form *element-groups* that describe the (group of) UI elements in all necessary details. After declaring element-groups, they can be referenced from the *condition* and *consequence* part of the rule (by the element-group ID). The declaration of element-groups is an implicit condition for their existence. In other words, a rule may only be triggered if – in addition to the other *conditions* – there exists a matching element-group in the current UI state.

The *condition* part limits the execution of rules according to the stated constraints. Conditions may relate to

a) attributes of the UM (*user characteristics*):
   The application of the rule depends on specific values, or a range of values of a user attribute, e.g. that the attribute "vision" has the value "bad".
b) previous events in the course of the simulation-run (*history*):
   The application of the rule depends on specific values or a range of values of properties in previous UI states. For each history condition (event), we need to state (i) how many simulation steps back this condition refers to and (ii) the property in question. The property has to be described in two separate *detail*-statements: one stating the property and value (or range of values) this condition refers to and one stating the element-group i.e. the "owner" of the property. For example, that the rule depends on the fact, that in the previous simulation step there was a SDS *prompt* that articulated a long output text, e.g. a condition referring to the UI prompt property "numberOfSyllables" with "minQuantity" 30.
c) dependencies between element-groups (*relation*):
   The application of the rule depends on the relation between declared element-groups, e.g. that the property "size" of element-group A is *greater* than that of element-group B.

It should be mentioned that the current implementation allows no conditions concerning the non-existence of UI elements, e.g. a rule that depends on the non-existence of a button with certain properties. However, this is no principle restriction of the approach and will be addressed in future developments.

Finally, the *consequences* part of a rule defines the effects of the rule on element-groups. An effect may be either *relative* or *absolute*. Relative effects manipulate the probability of the referenced element-group based on its current value. In contrast, absolute effects overwrite the current probability value of the element-group. Additionally, the effect may be restricted to a specific interaction of the element-group, i.e. the rule may only modify the probability of the interaction “LeftClick”.

Table 1. Excerpt from the available UI properties and user attributes (only entries relevant for the example in sect. 0 are listed here, for more details see e.g. [**Error! Reference source not found.**]). The GUI property *labelDistance* is used for checkboxes, and *conventional* for icons. The other GUI properties are used for annotating labels (links, icon-, and checkbox-labels).

Name	Value Range
GUI Properties	
contrast	5 levels
fontsize	5 levels
coding	consistent, inconsistent
colorCoding	true, false
underlineCoding	true, false
boldFontCoding	true, false
graphicalCoding	true, false
layoutGroup	[left,right,upper] navigation, content
labelDistance	high, low
conventional	true, false
User Attributes	
vision	good, bad
domainExpertise	high, low

Currently the rule mechanism is implemented with the *Java Rule Engine System (JESS)*. In addition to a basic framework of JESS rules, the XSD rule definitions are compiled into the system internal JESS representation. During simulation, the current context description – i.e. the UI state and UM – are converted into JESS facts to allow the rules access to them.

In difference to the JESS rules, the XSD-based syntax allows for more accessible rules with regard to comprehension and manipulation. For example, the XSD format can be used to automatically generate GUI editors so that practitioners who are unfamiliar with XML can also work with the rules (e.g. using the *Eclipse Modeling Framework (EMF)*, see [1]).

4 Example

In the following section we will describe an artificial example to illustrate the rule mechanism. For this example we use a minimal UI model consisting of one GUI dialog. The dialog contains several GUI elements that were chosen to illustrate the effect of rules caused by various different properties and values (see Fig. 3 and

Table 1). No user task knowledge is modeled in order to avoid increased or decreased probabilities for GUI elements due to the UM's reasoning phase: the input for the rule engine is equally distributed and differences in the output reflect solely the influence of the rule mechanism on the probabilities.

As example GUI dialog we use a *Hyper Text Markup Language (HTML)* web page containing various style variations of web links, icons and checkboxes. Fig. 3 shows the automatically imported UI model of the example web page: the type and locations of links, icons and checkboxes are automatically detected and annotated. Other properties of the GUI elements have to be manually annotated. Including some additional modifications, it took us (i.e. skilled users) about 5 minutes to create the final UI model for the example – excluding the time needed to create the HTML web page. Table 1 shows an overview for the GUI properties as well the user attributes that were manipulated when modeling the example. Besides the more obvious modifications and annotations (Fig. 3), we added the text on the right hand side of the 2 checkboxes as their *labels* where the upper checkbox label ("wide distance") has *high labelDistance* and the lower one ("normal distance") a *low labelDistance*. For the icons we marked the one on the left as *conventional (true)* icon and the other icon on the right as *not conventional (false)*.

As UM, we modeled two different user groups – that of stereotypical "young experts" and "older users" – by varying the 2 user attributes *vision* and *domainExpertise*: the group for *Experienced Users* receives *good vision* and *high domainExpertise* while the group for the *Trust Guided Users*, i.e. "old users", get *bad vision* and *low domainExpertise*.

For the rules that are used in this example, we draw on the current set that was developed for the MeMo workbench. The relevant rules that modify the probability distribution in the examples are listed in simplified form in Table 2: If the table row contains effects for both user groups, this implies two rule definitions. Effects that mark a relative *increase* of probabilities are marked with the symbol + and *decreasing* effects are marked with -. The *strength* of the effect is marked using 1 to 3 of the respective symbols for weak, medium, and strong effects. Some attributes in the column *GUI attribute conditions* have two values assigned which is signified by the | separator. In this case, the table row reflects (at least) two rule definitions in which all other attribute-value pairs stay constant for both rules except for the two-valued attribute. Since each row may reflect more than one rule definition, the last table column gives the amount of rule definitions that the corresponding row describes; the table summarizes 35 rules.

The corresponding rule definitions in their XML representation have similar form and complexity as the example rule in Listing 1. The rules described in Table 2 were derived from user experiments for *web site navigating*; they are based on experimental data augmented with expert knowledge (in analogy to [8]). While in principle the rule mechanism is open for MeMo workbench users to modify and create new rules, our goal is to establish a base set of broadly applicable and reusable rules so that users of the workbench do not have to create their own rules (see also sect. 5.2). For this reason, we used preexisting rules and do not report details concerning the time involved in creating the rules.

Table 2. Overview of rules that are used for the example. The columns *Experienced* and *Trust Guided* mark the effect of rules for the respective groups where *vis* + and *exp* + correspond to the user attribute conditions of *vision* = *good* and *domainExprtise* = *high*. Similarly, *vis* - and *exp* - correspond to the conditions *vision* = *bad* and *domainExpertise* = *low*.

Element Type	GUI Attribute Conditions		*Experienced* *vis* + | *exp* +	*Trust Guided* *vis* - | *exp* -	Rule Definitions
Link	colorCoding = true,	layoutGroup = content | left_navigation	+ + +	+	4
	contrast = high,	layoutGroup = content	+ + +	+ +	2
	contrast = low,	layoutGroup = content	-	- - -	2
	contrast = low,	layoutGroup = left_navigation	*NA*	- - -	1
	fontsize = big,	layoutGroup = content | left_navigation	+ + +	+ + +	4
	fontsize = normal,	layoutGroup = content | left_navigation	+ + +	*NA*	2
	fontsize = small,	layoutGroup = content	-	- - -	2
	graphicalCoding = true,	layoutGroup = content | left_navigation	+ + +	+ +	4
	underlineCoding = true,	layoutGroup = left_navigation	*NA*	-	1
	underlineCoding = true,	layoutGroup = content | left_navigation	+ + +	+	4
	contrast = low			- -	1
	contrast = medium			-	1
	fontsize = small		-	- -	2
Icon	conventional = false,	layoutGroup = content	- -	*NA*	1
	conventional = true,	layoutGroup = left_navigation	+ + +	*NA*	1
Check Box	labelDistance = high,	layoutGroup = content	*NA*	- - -	1
	labelDistance = low,	layoutGroup = content	*NA*	- -	1
	layoutGroup = content		- - -	*NA*	1

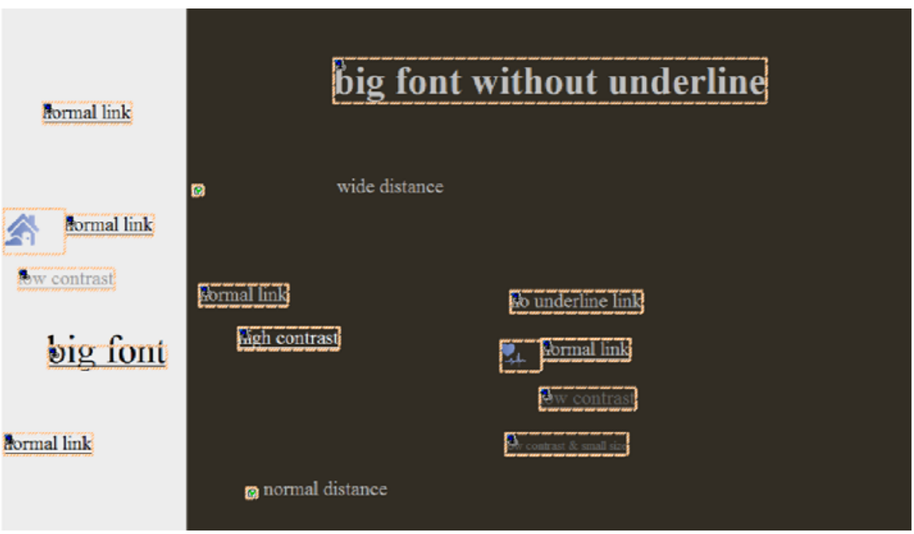

Fig. 3. Automatically imported UI model of a web page with annotated locations for GUI elements (hyper links, icons, checkboxes)

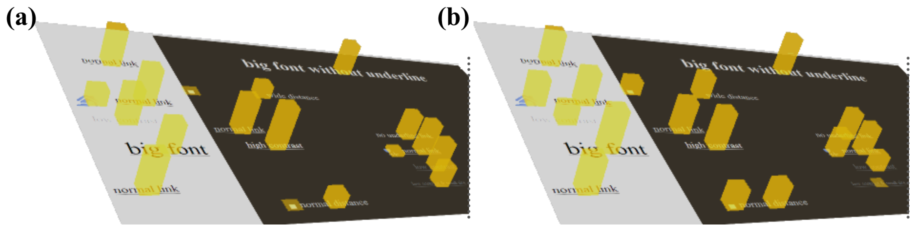

Fig. 4. Probabilities modified by the rule engine superposing a screenshot of the example web page: (a) *Experienced Users*, (b) *Trust Guided Users*. Note that the probabilities for the checkboxes and their labels – as well as for the icons and their labels – are shown separately; the according total probability is the sum of the probabilities of the element and its label.

Fig. 4 shows the probabilities returned by the rule engine displayed over a screenshot of the example web page. The figure shows the probabilities for the icon-links and their labels, as well the checkboxes and their labels separately, i.e. the total probability for the icon-links and the checkboxes is the sum of their own probability and the probability of the corresponding label. In Fig. 4 we can see distinct differences for the probabilities in the lower right group of GUI elements (with low contrast, small font size properties) between the 2 modeled user groups as well as for the 2 checkboxes. The diagram in Fig. 5 highlights the differences between the two modeled user groups with the highest difference on the left. The diagram confirms the impression from Fig. 4, that the modeled "older users" are more likely to leave GUI elements with low contrast and small font size unused and "profit" more from large font sizes, while the "young experts" tend to ignore checkboxes for the navigation task. Also, in difference to the "old users", the "young experts" make a clear distinction between *conventional* and *unconventional* icons.

The resulting probabilities for *high contrast* links in the *content* area show that "old users" are *less* likely to use them. This difference is caused by the second rule in Table 2. The rule definition is based on the analysis of a web navigation experiment (analogous to [8]) that states that *Experienced Users* are more likely than *Trust Guided Users* to use a high contrast link in the content area. A possible explanation could be that, on the one hand, the visually impaired *Trust Guided Users* may still profit more than the unimpaired group from the high contrast in the sense of perceptual improvement. But, that on the other hand, the expert users, due to their experience, interpret high contrast links as especially important and consequently are more likely to use them.

In summary, the example illustrates that the MeMo workbench supports rapid creation of UI models and UMs reflecting different user groups. Additionally, the rule mechanism applies complex modifications to the interaction probabilities depending on the UI element properties and the UM attributes for the modeled groups.

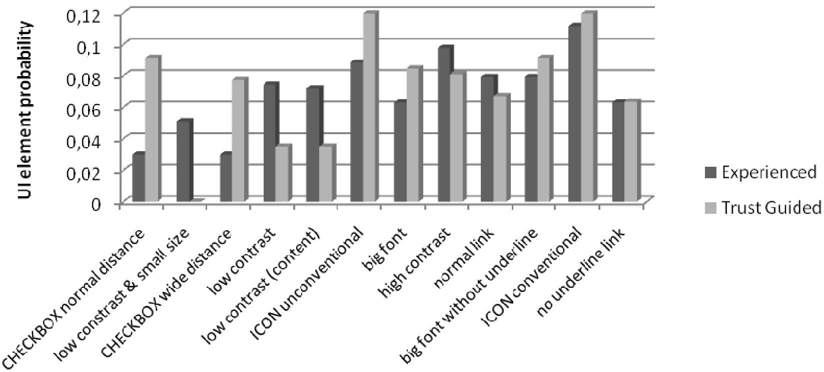

Fig. 5. The resulting probabilities of the two modeled user groups of *Experienced* and *Trust Guided Users* for GUI elements in the example. The GUI element with the highest difference between the groups is to the left, and the rest is ordered correspondingly. When several GUI elements of the same type (e.g. "normal link") have the same probabilities, only one entry is shown in this diagram.

5 Discussion and Future Work

The main intention of the approach described in this paper is to enable IT practitioners to test their applications in an early stage of the development process. Therefore, we describe mechanisms to define and execute rules on simulated user interaction for the purpose of automated usability evaluation. Conditions of these rules take user attributes and UI element properties from the current simulated system state or from previous states into account. Consequences of the rules are used to modify the probability-to-be-used of UI elements.

In [9] the modeling of a software system and replication of observed experimental data gives support for the general feasibility of the described rule mechanism for modeling and predicting usability problems. However, a number of questions concerning the application of the rule mechanism and its advantages need further investigation and are therefore discussed in more detail in the following.

5.1 Description Level of Rules

The description level of the rules is rather abstract: rules operate on (abstract) user attributes and (observable) UI element properties. In terms of the "real world", the rules take *behavioristic observable* properties into account in order to determine their effect.

Still there is some variance for the level of abstraction that directly affects the validity of simulations as well as the kinds of usability questions that can be answered by simulations: rules can draw on low-level user attributes (e.g. the user's *luminance contrast perception*) as well as highly abstract attributes (e.g. the user's *affinity for technology*). Accordingly, analyses of rules that fired during simulation allow only inferences – regarding usability problems and solutions – on the same abstraction level as the rules that were used for the simulation.

Rule mechanisms for similar applications, i.e. for the simulation of exploratory behavior, are mostly employed in the context of *cognitive architectures*. In general, rule mechanisms in cognitive architectures are less abstract. They are mostly concerned with inner cognitive processes, i.e. they operate on and influence inner cognitive properties and variables that are not directly observable. As a result, applying cognitive architectures in the context of usability simulations usually requires very specific and task dependent rules. These specific rules function as hypothesis for user strategies and – if sufficiently verified against experimental data – can provide explanations for user behavior and for the cause of non-optimal user decisions that may signify usability problems.

In contrast, the more abstract rules from our approach relate usability problems to a set of user attributes and UI properties. Here we argue that in the context of uncovering usability problems, this is usually sufficient information to investigate and fix problems with the UI and underlying tasks. Especially under the premise that a high abstraction level makes rules more readily intelligible to non-experts of cognitive science and can thus provide sufficient information for IT practitioners to further investigate highlighted usability issues. This can be achieved by analyzing *aberrant* task solutions (with regard to the optimal solution) and examining the rules that caused aberrations which then provide information for possible usability problems on the same description level as they were specified.

Currently, we also explore, if and how inner cognitive attributes of the UM can be integrated into our rule mechanism. In an experimental implementation, rules can access and manipulate *intentions* and *Dynamic User Attributes (DUA)*. In difference to “normal” static user attributes (e.g. *visual acuity, tremor, education*), DUA (e.g. *attention, irritation, time pressure*) can change their value in the course of the interaction simulation. For instance, a history rule may state that the DUA *irritation* will rise, when in a certain sequence of interactions, the UM fails to find a particular *information particle*. Or, during a simulation, the UM may first have the intention to *accomplish the given task*, but then temporarily change the intention to *ask for help*, due to a rule that checks, if the irritation of the UM surpasses a certain threshold.

5.2 Creating Rule Sets

A basic assumption in our approach is that the complex influences of properties and attributes on the probability distribution can be modeled using a large number of rules which themselves are comparatively simple (see example in Listing 1). The creation of a rule set that reflects complex influences can be managed by iteratively extending the set and adding individual comprehensible rules.

However, with increasing number of rules, their combined effects become harder to judge by practitioners when extending the rule set: given a set of attribute and property values, it becomes harder to foresee the effect of the rules on the probability distribution. For small rule sets or simulations that are intended to approximate user behavior only roughly, this manual process may still be feasible. In order to reach sufficiently faithful and plausible simulations, considerable effort to validate the effect strength of rule definitions is necessary, e.g. by using machine learning for deriving the strength from experimental data. Although we were able to apply the GUI-related rule set and make predictions for 3 UI models in the context of the SmartSenior[3] project, so far we have not been able to validate the GUI-related rule set against experimental results due to lack of usable experimental data from user tests.

A further problem for large rule sets is that modeling the dependencies between properties and between attributes quickly becomes cumbersome. In principle, each possible value of the dependent attribute – or property – requires its own rule definition, potentially resulting in an exponential number of rules for representing the dependency.

There is no tool support yet, but for the most part this could be overcome by allowing the practitioner to specify a condensed definition of the dependency and then use this to compile the necessary rule definitions.

Despite these issues, we propose that the high abstraction level of the rules makes them good candidates to be used and reused in simulations for different UIs: They exhibit a comprehensible syntax and work with generic definitions of UI elements and user attributes, which offer the possibility to adapt them to new areas of application. However, specific criteria that allow deciding if a specific rule can be reused in other simulations still need further investigation.

Due to these considerations, we are planning to establish a base set of validated and reusable rules that are applicable to a wide variety of UIs and that provide reasonable results for uncovering usability problems with these UIs.

5.3 Interpretation and Use of Distributions

In terms of the *Model Human Processor* (*MHP*, see [5]), the use of the rule engine is applied during the *cognitive processing phase*. The modified probability distribution is then directly used to compute the UM's interaction decision during that phase.

Several studies exploring the effect of age in web browsing tasks suggest that the difference between younger and older users is less pronounced in task success but more in completion time and necessary steps [6, 10, 12, 28].

Consequently it seems more likely, that e.g. GUI elements with low contrast have not per se a lower probability to be used, but are less likely to be looked at and therefore evaluated. For instance, such UI elements might not be perceived due to "overlooking" or prematurely selecting another interaction before inspecting all available UI elements. In terms of the probabilistic simulation process, this implies that first a probability distribution for the *perception* is calculated and then one for the *cognitive processing*.

As a work in progress, we extended the MeMo workbench to incorporate three processing phases following the MHP for *perception, cognition, and motion* [23, 26]. As a result, probability distributions calculated by the rule engine employing appropriate sets of rules are used separately in the different phases. This allows modeling sequential dependencies more naturally than using a single probability distribution for calculating the UM's decision making.

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[3] `http://www.smart-senior.de/enEN/`

6 Conclusion

In this article, we presented our ongoing work on model-based automated usability evaluations with the help of the MeMo workbench. We focused on the description of user simulations that are affected by deficits characteristic for old age. The main goal of these simulations is to find usability problems related to these specific needs. Therefore, we have incorporated a rule-based approach which employs user attributes and UI properties in rules for calculating probability distributions. These probabilities are then used to determine user interactions of exploratory behavior. In difference to existing approaches, e.g. cognitive architectures, the rules capture more general aspects of usability knowledge. Accordingly, our approach is less task-dependent and can be transferred to other tasks and even UIs more easily while maintaining reasonable precise predictions about usability problems.

We conclude by asserting that our approach, as well as other existing approaches, cannot replace user testing. Instead, our approach aims to considerably reduce time and effort by enabling early simulations and provide early usability feedback for practitioners during the UI development.

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Usable User Interfaces for Persons with Memory Impairments

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Abstract. Taking active part in the self-serve society is required as long as possible. Information technology can be used to support this. However, little or no familiarity with information technology represents a major barrier. Another serious hindrance is low accessibility of user interfaces, i.e. solutions which fail to follow the principles of healthy and intuitive design. In this paper, we present design principles that can make an AAL self-service technology for elderly accessible. These principles form a set of guidelines that has been applied in the development of the assistive technology Mylife. Mylife aims to support independence for older people with reduced cognitive function by giving them access to simple and intuitive services that are adapted to their individual needs and wishes. Mylife uses services available on the Internet, such as calendar, photo album, music, news and communication, and presents them together on everyday devices with a touch screen. Mylife is flexible and can be gradually modified to follow the user's cognitive development. Caregivers administer the setup, personalisation and content management of the Mylife product via a web-interface. The web-interface allows the caregiver (secondary end-user) to administer the setup of the primary end-users' Mylife device, including personalisation and daily content management.

1 Introduction

1.1 Background

Taking active part in the self-serve society is required as long as possible. Information technology can be used to support this. However, little or no familiarity with information technology represents a major barrier for many people.

Another serious hindrance is low accessibility of user interfaces, i.e. solutions which fail to follow the principles of healthy and intuitive design. One example of established guidelines for accessible design is the Principles for Universal Design [1], developed by the NC State University College of Design (USA). These principles support the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialised design.

In this paper, we present our work focussing on the design and development of an assistive technology for persons with memory impairment (dementia). Based on available guidelines, such as those mentioned above, we have developed a set of practical guidelines to make an AAL self-service technology for elderly as accessible as possible. In the context of this work, the elderly may be both primary and secondary end-users. Primary end-users are older persons with cognitive impairment, for example persons with early dementia, who live at home. Secondary end-users are the persons who administer and manage the assistive technology on behalf of the primary end-users. They may be spouses, children or other relatives, social workers or formal care givers.

Our main focus is on cognitive aspects of usability and accessibility. These result from user involvement during the design process of the initial Mylife-prototype (AAL Joint Programme Call AAL-2010-3, Project no. AAL 2010-3-012 Mylife: Multimedia technology to support independence for and participation by people with dementia [2]).

1.2 Mylife in a Nutshell

Mylife aims to support independence for older people with reduced cognitive function by giving them access to simple and intuitive services that are adapted to their individual needs and wishes.

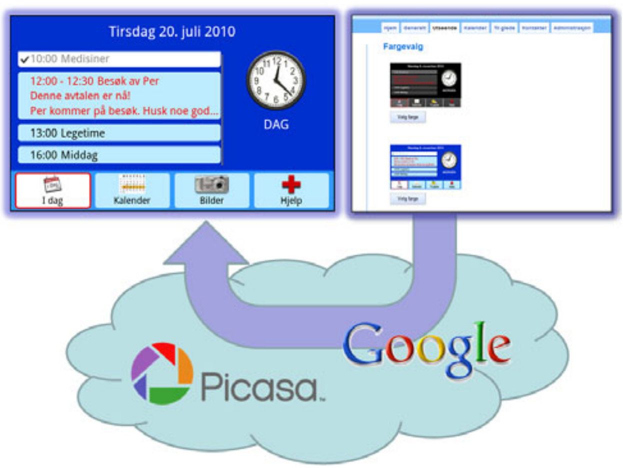

Fig. 1. Mylife services presented on primary end-user's device (upper left). Secondary end-user's web for configuration and administration (upper right), including personalisation (appearance and choice of services), and feeding in content, e.g. appointments/reminders to calendar, or photos to album(s).

Mylife uses services available on the Internet (Figure 1), such as calendar, photo album, music, news and communication (help), and presents them together on everyday devices with a touch screen. Tablets that are mounted in a stationary docking station, or mobile or hand-held, can be used to display Mylife (Figure 2).

Mylife is flexible and can be gradually modified to follow the user's cognitive development. When the primary end-user's capacity or interest decline, services (functionalities) can be simplified or removed.

Caregivers administer the setup, personalisation and content management of the Mylife product via a web interface. The service offered by Mylife supports time-orientation, communication and recreational activities. In Figure 1, the conceptual model of the Mylife product is presented. In Figure 2, the Mylife prototype is in use.

Fig. 2. The prototype of the Mylife product in use. Touch-screens in different sized can be used as primary end-user's device.

1.3 Method

The initial Mylife prototype was developed in research pre-projects during 2009-2010, financed by the IT Funk Programme of the Research Council of Norway [3]. This development included requirements analyses, conceptual development, paper prototyping [4] for the design of user interfaces, software development, and end-user and expert evaluations for the HCI-solutions.

Special attention was paid to the use and usability of touch-screens, including accessibility for the navigation and the presentation of information and functionality. End-user and expert evaluations included focus groups with persons suffering from memory impairment (e.g., MCI[1] or dementia), dementia expert panels, demonstrations at senior centres, and individual user trials. Requirement and accessibility design solutions for the secondary carer's web originate from other projects with similar web-design challenges, i.e. projects which include development of web-solutions for secondary end-users such as family care-givers or health personnel.

The initial Mylife prototype was fed into the Mylife-project and is currently undergoing continuous development and evaluation in the user tests and field trials during 2011-2012. In the remainder of this paper, the guidelines principles that have been developed in the Mylife-project are presented.

2 Design Guidelines

2.1 Cognition and Accessibility

Accessibility problems are of particular concern to older people and people with cognitive disabilities. Indeed, an OECD-report concludes that age exerts a strong influence on computer use, showing a significant decline after age 45. The findings

[1] Mild Cognitive Impairment [5].

show a clear negative association between age and cognitive skills [6]. Cognitively disabled people have difficulties interpreting what is seen or heard and/or difficulties making mental connections between different pieces of information, or have trouble with abstract reasoning. The type and degree of cognitive impairment can vary widely. Well-known cognitive impairments are dyslexia, dyscalculia, learning and language disabilities, and dementia. [7]. Cognitive skills or abilities, or the lack of these, thus define an important area of concern for the accessibility design of assistive technologies for older persons.

2.2 Guidelines for Cognitive Accessibility

The principles that have been identified as important, and applied for the accessibility design of the Mylife user interfaces are:

1. Enable gradual simplification.
2. Enable direct manipulation.
3. Offer alternative modalities.
4. Simplify the language.
5. Make visualisations relevant.
6. Enable alternative presentation styles.
7. Model real world artefacts and their behaviour.
8. Make it easy to start from the beginning.
9. Acknowledge external communication.
10. Let the users be users.

When developing these principles, we have frequently consulted the Principles for Universal Design [1]. In the following, we will give concrete examples of what these principles mean in practice, and how we have realised them in the Mylife prototype's user interface.

2.2.1 Enable Gradual Simplification

Persons with dementia will experience increasing cognitive loss. In order to compensate for this development, the service should be designed to allow gradual simplifications. Mylife is designed so that both categories of services and content within these can be simplified. The main service structure consists of services Today, Calendar, Fun (with several sub-categories) and Contact. This selection can be reduced to any number of services, according to the primary end-user's needs and wishes. The simplest possible alternative is one single service, e.g. Today, or just one photo album.

In Figure 1, two versions of Mylife are shown: The stationary table-top version contains two services, visible as two menu buttons at the bottom of the screen. The hand-held version contains all four categories of services, shown as a "full row" of menu buttons at the bottom of the screen. Also in Figure 6, a simplified Menu is shown.

2.2.2 Enable Direct Manipulation

Traditional PCs with key-boars and manipulation devices (such as mice and joy-sticks) may be difficult to use for persons with low ICT-skills or with a cognitive im-pairment. Indirect manipulation of objects and functions on the screen challenge the cognitive apparatus. The new development of touch-screen based devises, such as smart phones and tablet PCs, offers help to many users. Our empirical research with elderly users indicates that direct manipulation on touch screens shortens the learning period remarkably, is less "frightening", and supports intuitive use. In Mylife, keyboard is totally eliminated, and all use by primary end-users is based on touching the screen. The challenges are connected to the size of touchable areas which have to be so large that they are easy to hit even with slightly shivering hands. Therefore, this type of equipment requires careful interaction design even if the direct manipulation interface would appear as "automatically simple" at the first glance.

Even the physical access and use is made easier on touch screens: Such assistive technology as Mylife may be placed anywhere at the home, e.g., in the kitchen or on the coffee-table. It is clearly preferable that only one piece of equipment occupies the physical space. Moreover, hand-held tablets allow a certain freedom of movement indoors. (Figure 2).

2.2.3 Offer Alternative Modalities

In case of cognitive challenges, multi-modality may support the user. Obvious alternatives are text, images and sound. The user should be able to choose text and other information elements to be read aloud. In Mylife, such texts are the calendar appointments and reminders, the menu choice buttons or the photo texts (Figure 3).

For the buttons in menus and other choices, both text and icons are clearly preferred by the informants. Many of them wish that the button texts are in addition read aloud, i.e., three simultaneous modalities should be available.

Fig. 3. The current Mylife prototype includes both icons and text for all menu choices at all menu levels (here in Norwegian)

2.2.4 Simplify the Language

Both in expert evaluations focus groups and individual user trials, the use of language has been an issue. The main task during the development of the Mylife prototype has been to find as simple and short expressions as possible without losing information. (Here, we focus on the language used in the text elements of the Mylife system itself, not the texts that are written by secondary care-givers in the calendar or photo albums).

Fig. 4. "Today" of Mylife showing final, simplified expressions (here in Norwegian)

Two examples of simplifying the language are the menu buttons, and showing the time of the day. When designing the menu buttons, the tasks has been about synonyms. For example main well-being category as shown in Figure 3 is about entertainment. Examples of the development of compact terminology are (Figure 4):

```
Entertainment → Pleasure → Fun / Joy (English Mylife)
Underholdning → Til glede (Norwegian Mylife)
Unterhaltung → Vergnügen → Spaß (German Mylife)
```

The expression for the time of day has been treated similarly. Here, one word was enough instead of a short sentence:

```
It is day  → DAY (English Mylife)
Es ist Tag → TAG (German Mylife)
Det er dag → DAG (English Mylife)
```

2.2.5 Make Visualisations Relevant

One of the pre-project activities preceding the Mylife-project was analysis of icons. As mentioned in Chapter 2.2.3, all menu choices are visualised. In order to find the best possible icons, rather large sets of alternatives have been ranked by potential end-users. The approach has been two-fold: The informants have been asked what they think different icons represent (e.g., smileys, playing cards, note, camera etc.), and they have been asked to rank alternative icons for one certain object or class of objects (e.g., different types of telephone for communication, or different types of cameras or photos for photo albums etc.). This type of approach gives valuable information of the relevance and acceptability of visual material. Our conclusion here is that finding the best visualisations requires collaboration with the actual users; there is no such thing as "universally best icon for music".

Two particular findings deserve to be mentioned, however: 1. Old-fashioned icons for camera or telephone were clearly unpopular, not because of difficulties in understanding the *meaning*, but because of the underlying signal of being *designed for old users*. Elderly people use digital cameras and mobile phones. Some of them prefer digital representation of time instead of analogue, and so on. Modern artefacts should be used as icons for modern people. 2. Symbols and icons that computer scientists have established as standard representations, such as a picture of a house ("home") in browsers for starting page, do not communicate well (if at all). These have to be avoided.

2.2.6 Enable Alternative Presentation Styles

In this paper, usability and accessibility for persons with dementia are in focus. For them, visual clarity is important to combat cognitive challenges. Many elderly end-users have also visual impairments. This has to be taken into account in the design of the user interface. The pieces of advice given in the previous chapters all contribute to this. Visual clarity can be enforced by high contrast. For those users who prefer this, such alternative should be offered.

In addition to the requirements set by low vision, alternative presentation styles may satisfy the end-users' requirements concerning aesthetics. In Figure 5, two high-contrast variants of Mylife are shown.

2.2.7 Model Real World Artefacts and Their Behaviour

Persons with cognitive challenges make an effort when they use information technologies. The conceptual models and the interaction differ from the operation of most other technologies or everyday artefacts. This fact leads us to the recommendation to model real world and the behaviour of known objects.

Fig. 5. Black and white high-contrast user interface of Mylife

Mylife examples of this are the clock (that is shown in many of the figures), the monthly calendar, and the photo album. The calendar resembles the design of traditional wall-calendars, and the photo albums are operated by commanding Mylife to “leaf over” (Figure 6). Most test users have preferred this explicit command-mode of leafing through the album, compared to other options on a touch-screen, such as continuous panorama by “dragging” photos over the screen.

Fig. 6. Mylife photo album with leafing buttons on each side of the photo

2.2.8 Make It Easy to Start from the Beginning

Navigation is known to be one of the most critical usability factors. The main navigation should be placed identically on all “pages”, and critical functions should never disappear. In Mylife, Today as shown in Figure 4, is the starting page, and always visible. This enables the user to start from the beginning at any time. The interface should also clearly express where the user is in the dialogue, and which “tasks” are active. In Mylife, this is implemented as differently framed and coloured menu buttons (e.g., Figure 4.)

2.2.9 Acknowledge External Communication

In the current version of Mylife, mainly two functionalities connect explicitly to external resources. These are News and communication (Help). News is electronic newspapers that are down-loaded from predefined URLs. Depending on the network connection and the amount of data to be downloaded, the user may need to wait for some seconds. Understanding that this is not “inside” Mylife is an important usability factor for the end-user. This is illustrated by a progress-bar as shown in Figure 7. The progress-bar also tells to the end-user that a newspaper is being *fetched* from outside the Mylife. (The word ‘down-load’ is not used in order to keep the Mylife-language simple and understandable; cf. Chapter 2.2.4).

When the Mylife-user needs to contact her/his care-givers, the Help-functionality sends a message to pre-defined recipients. Acknowledgement of this very communication is then shown to the user. Otherwise the user would not know is something happened or not, and might become uneasy.

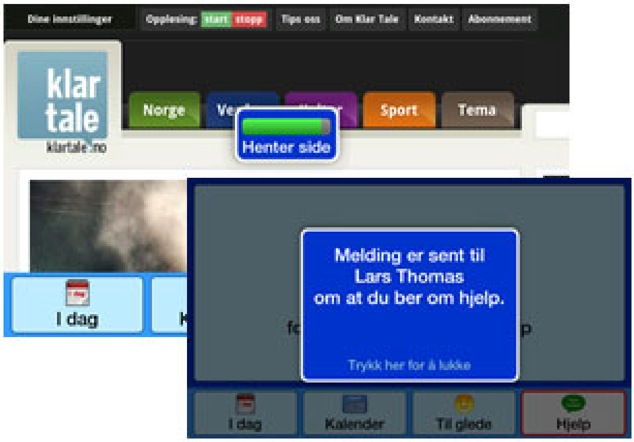

Fig. 7. Progress-bar showing the status of down-loading a newspaper. Acknowledgement of message sent to contact person (care-giver).

2.2.10 Let the Users Be Users

As mentioned earlier, the configuration, administration and content management of the primary end-users Mylife system is conducted by the secondary end-user through a web-interface. The carer's web allows the secondary end-user to choose the appearance, select and delete functionalities, add and remove content, maintain lists of Help-message recipients etc. (Figure 1). The primary end-user, on the contrary, does nothing of this; he/she simply uses his/her Mylife.

This division of labour is implemented in order to make the primary end-users use situation as distressing as possible. Also, the care-givers know the primary end-user, and are likely to able to make necessary adjustments even if the primary end-user could not communicate all needs and wishes. "Engineering tasks" are to be allocated to the capable. In the following chapter, advice concerning web-interfaces, such as the secondary carer's web, is given.

2.3 User Guidance for Increased Usability

User manuals and operating instructions is also an important dimension of the Mylife-usability. One of the explicit goals of the Mylife-project is to produce understandable, inspiring and innovative user instructions. On-line user manuals and operating instructions will be designed to support both primary and secondary end-users.

An overall ambition of the Mylife-project is to implement an interaction design that makes user instructions superficial. The realistic approach implies that this will not always be the case. For high-value user guidance, following alternatives will be implemented for the secondary end user (carer's web): 1. Immediate contextual help.

2. Down-loadable “how-to” manuals. 3. Screen casts. 4. Frequently asked questions. For the primary end-user, simple manuals showing each “page” of Mylife with a simple explanation.

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Tablets for Seniors – An Evaluation of a Current Model (iPad)

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Abstract. Internet usage in Austria varies between age groups in a way that only about 30% of older users above 60 have access to Internet services compared to nearly 100% in the age group between 14 and 30. This digital divide exists because of technical, social and economical barriers that affect especially older users. Weather or not current tablets have the potential to minimize these barriers was the central question behind the usability study described in this paper. The study undertaken involved 11 seniors (60+) and targeted to evaluate the general usability and acceptance of a selected tablet. The results of the study show high acceptance and satisfaction rates among the user group and hence suggest a future focus on the development of tablet based applications for seniors as well as initiatives to conquer the information demand of the target group.

Keywords: tablet, digital divide, older people, e-inclusion, iPad usability.

1 Introduction

Web-based services have become an essential part in everyday work and private life. Nearly 100% of the Austrian population aged between 14 and 30 years is making use of web services, but for those aged 60 years and above, Internet access is still very limited. According to recent studies by GfK Austria [1] and the Initiative D21 in Germany [2] only one third of the population above 60 years uses the Internet.

The resulting „digital gap" excludes elderly people from parts of public life. High entry thresholds are among the main reasons that keep older people from using the Internet. Those thresholds include high respect of new technology caused by a lack of experience and the fear of depending on technically more experienced people in case of possibly occurring problems. Technical hurdles like highly complex user interfaces, high acquisition and maintenance costs are further major barriers for Internet newcomers. [3,4,5]

1.1 The Project MyTablet

The main target of the project "myTablet", funded by the Internet Foundation Austria, was to evaluate if the current generation of tablet PCs like Samsungs "GalaxyTab" or the Apple "iPad" could lower the barriers to access the Internet. Therefore the hypothesis was introduced that people aged 60+ without previous experience with personal computers and Internet profit from using tablets because of their less complex user interface when compared to a PC.

To validate this hypothesis a usability study has been conducted together with eleven (n=11) elderly people within the "Living Lab Schwechat". The following chapters describe the methodology used and results gained during this study.

2 Usability Study

The study was based upon the following research questions:

1. How do the test users rate the usability of the device in general and the user interface in particular?
2. Is it possible for the users to use the most common Internet applications such as information research and communication via e-mail on the tablet independently after only getting a short introduction to these features?
3. How extensive does this introduction have to be to enable Internet newcomers to use these basic functions independently?
4. What are the perceived advantages and disadvantages of the tested technology / the device?

2.1 Description of the Trial Participants

Inclusion criteria of the target group were people above 60 years (age > 60) without previous Internet or PC experience, but a general interest to start "getting online".

A group of seniors at the same age who were already using the Internet have been included into the study as well to be able to draw comparisons between experienced Internet users and newcomers and to gain feedback about the differences in using a personal computer and a tablet.

In total 11 persons (n=11) with an average age of 71 years have been involved in the study, four of them male, seven female. Five participants already gained at least basic experience in using the Internet via a PC, six did not have neither experience with a PC nor the internet.

2.2 Methodology

Single user interviews were conducted to evaluate the scientific hypotheses. During the interviews the users were asked to complete concise predefined tasks by using functions of the tablet. The tests were recorded by video and notes were taken by the test supervisor during the task completion for retrospective performance analysis.

2.3 Test Setting

The Apple iPad 1 was used as an example of a tablet since it is leading the market and user studies with a broader target group are already available as reference [9,15]. **Fig. 1** shows the test object and the test setting during the single user study.

Fig. 1. Test setting during the single user interviews

Prior to the test the tablet was customized to meet the needs and interests of seniors based on a previously conducted requirements analysis. Appropriate applications were selected, system applications that could confuse the participant were hidden and system settings were preconfigured as far as possible.

The following applications were considered as central and chosen for the test:

- Safari – web browser
- Mail – email client
- Karten – Google Maps application
- Youtube – video sharing portal
- Billa – online portal of a well known supermarket chain in Austria
- Fotos – picture viewer
- Quick-links to: weather, news and Google search.

The following **Fig. 2** shows a screen shot of the user interface used for the test including the installed applications.

Fig. 2. Screenshot of the main user interface

2.4 Test Flow

The test was split into three parts; an introductory part, the main part including the execution of test tasks and a final part including also a final survey.

During the introduction the project and the tablet were explained to the test user. The explanation of the tablet followed a predefined workflow including all necessary information to conduct the following user tasks.

Directly after the introductory part the users were asked to perform predefined tasks while verbalizing their thoughts according to the “thinking aloud”-method [6,7]. For more complex tasks, scenarios were used to further visualize the goal of the tasks to the user. One example of the used scenarios:

- “Imagine that it’s flu season and you are not sure whether you should get a vaccination or not.”

The purpose of using such scenarios was to create a situation where the user could make use of the device during his / her daily life so that the assigned tasks make more sense to him / her. One task for the above-mentioned scenario has been:

- “Please search for information about flu vaccinations in the internet.”

Every task consisted of several certain steps that needed to be done in the correct order to fulfil the task correctly. Each step has been observed and logged for evaluation by the researchers conducting the study. The researchers did not influence the test participant while performing the task, but in case of problems the user could not overcome, a small hint was given following the „obtrusive observation“ approach [10] so that the person could continue with the task.

To be able to set a relation between the objective observation of the researcher and the subjective feeling of the test participant, the user was asked after each task about his / her personal impression on performing the task:

- “Did you have the feeling that this task was difficult?“ / „Did you experience some ambiguities while conducting the task?”

Each participant has performed the following tasks:

1. Turning on the tablet and looking for the weather forecast using a quick-link on the home-screen
2. Retrieve the latest news (via a quick-link on the home-screen)
3. Searching for information on selected predefined topics using Google-search
4. Finding an address on a map (using the Google-maps application)
5. Reading an e-mail
6. Writing an e-mail to a predefined recipient
7. Searching for a predefined video on YouTube

Subsequent to the tasks a qualitative interview [8,9] has been conducted to discuss central usability aspects like readability of the elements on the screen, ease of use of the gesture control and the virtual keyboard and to get general feedback about the device and its features.

2.5 Results

In the following paragraphs the knowledge gained by the general course of the trial, the conduction of the tasks, the final interviews and the user comments during the whole test procedure is summarized.

Test flow. Depending on the previous knowledge the introduction to the tablet and its features took between 15 and 40 minutes per test participant. Surprisingly the amount of time needed to perform a certain task did not vary much between experienced Internet users and newcomers. The average time to conduct all tasks was about 60 minutes including the interrogation after each task and further explanations. This means that every participant has been using the device for about 1,5 hours before answering the questions of the final interview.

Performance results. Both experienced and novice users have been able to understand and independently conduct the assigned tasks after a short introduction. As expected it showed that Internet newcomers made more mistakes than the experienced user group. For more complex activities like web browsing and writing e-mails a more detailed introduction would be essential. The following circumstances highlighted this fact:

- The representation of web links can vary largely between different websites (they might look like a button, like a picture, have different text styles) therefore they are not always perceived and recognized correctly. Especially selecting the right link in Google-search results has been very difficult for novice users.

- Simpler applications and features such as gesture control were quickly learnable and useable by the target group. Especially the intuitive usage of the so called "pincer gesture" – a gesture using index finger and thumb to enlarge areas on the screen - has been astounding. Some participants even used this gesture as a solution to enlarge small web links on the screen without being told that it could be used for this purpose.
- Unfortunately anglicizes cannot be avoided completely when using the World Wide Web. This became a hurdle for some users lacking knowledge about the English language. For example some users had problems associating „YouTube" with watching videos.

The following difficulties are caused by misunderstandings of the tablet's user interface, which can be applied in a similar way also to Android based devices:

- For some users it was hard to distinguish between "back to the main screen" and "back within the web browser".
- The way input fields work is not easy to understand for novice users. (Tapping into the input field to activate the virtual keyboard and then press "enter" to start a certain process)

- While writing an e-mail worked quite well for all participants, some complained that the feedback given by the tablet when an e-mail has been sent was not clear enough.

In case a problem occurred during a task, the correct solution was explained once more to the participant to avoid an influence on the test results by repeating the same mistake more often. In fact most of the mistakes did not occur in later tasks anymore.

General Usability of the Device. All users stated that the tablet in general was very easy to use, although most novice users added that it takes a little time to get used to the handling of the device, but it was easier and faster than they expected because of the logical workflow and manageable functional range. „When you've exercised a bit, it's easy – you just have to learn what happens when you press on a certain item." "You just try and hope that it's right and most of the time it's right."

It was highlighted as a positive attribute that the device is not intimidating as it does not look like a complex machine.

Although all experienced Internet users said that the tablet was very easy to use, only half of these users would prefer to use a tablet instead of a common personal computer. It was stated that some tasks are more complicated to perform using a touch screen and that the integrated e-mail-client was not as intuitively usable as the one they are used to. It was emphasized, as a positive aspect that starting an application works very easy and faster than on a PC. „You tap on it and the application launches immediately."

Central Aspects of Use. The participants were asked to rate the following aspects in the use of the tablet according to the scholar system i.e. from „very good" to „fail": (the value in brackets shows the rating).

- Readability (very good)

Being able to enlarge the screen content as required in an easy way resulted in the highest mark („very good") for readability. „Reading is magnificent, because you can enlarge anything you want." The easy to use magnifying feature thus became an important additional benefit in comparison to a conventional PC for this user group.

- Writing (good)

It was highlighted positively that the letters on the onscreen keyboard were quite big, but writing itself was not that easy for many users – especially when they were not used to typing on a typewriter. Although writing took quite long for those participants they were positive that it would improve after some time of practice.

- Gesture control (good – very good)

Some participants had slight problems when tapping on the screen. Remaining too long at the same screen position automatically triggers secondary functions such as

„copy / paste text“; swiping slightly with the finger when tapping often makes the gesture unrecognizable for the tablet which can be a problem for people with tremor.

Enlarging and minimizing screen content using the pincer gesture worked out very well for all participants and has been rated as very easy and intuitive (those who had motor disabilities in one hand just used both hands to perform this gesture) as well as scrolling and turning pages by swiping with a finger.

3 Conclusion and Discussion

The results of the usability study showed that tablet PCs really can lower some of the initially mentioned hurdles to access the internet and therefore make it easier to use online services and „make a step into the digital world“ independently for people who are inexperienced in using a PC, in using the internet or both. Due to the limited number of participants (n=11) only qualitative conclusions could be drawn.

An essential advantage to conventional PCs proved to be the non-complex, less technical and less daunting look and easy handling of the device, which are both primary reasons for the high respect this user group has for technical devices.

Additionally the touch screen interface and the lower amount of features enabled even Internet newcomers with low technical interest to use the device.

All participants reported that they had a very positive impression of the tablet. The possibility to autonomously learn new features furthermore made some people state that they now feel more confident in technical solutions in general.

Some general hurdles could not be overcome by using the device alone. The device had to be set up especially for the study and the participants got an initial introduction, which would usually not be the case after buying the device in a shop. Hence support is still necessary in a real life scenario and could be given by a friend, a relative, a carer or an institution.

4 Outlook

At the time of the study (1st quarter 2011) there have already been numerous applications for the test device in German, which can typically be found in AAL research projects like cognitive training games to prevent dementia. Tablets thus could soon contribute to bring research projects in the field of AAL to market in an easier way and in this way lower the gap between market and research. In future projects of the research institute CEIT RALTEC this approach will be intensified.

Special tablet PC courses targeting elderly people similar to those already offered for laptop and PC would facilitate the access for this user group. According to the study described in this paper telecommunication provider could benefit from offering a tablet especially designed for elderly people.

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Two Steps Forward and One Step Back? on the Acceptance and Use of AAL Technology in Households

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Abstract. Many projects in the field of Ambient Assisted Living (AAL) employ home automation technology and the procurement of domestic support services to enable older adults to live independently as long as possible in their familiar domicile. The specific needs of individuals and the constraints of the elderly, to actually use these technologies and services, are however, often not observed. In two pilot projects, the acceptance of home automation and AAL technology and of services was examined by sociologist of the University of Kaiserslautern. The willingness to use the technologies and the potential use of services are high, but the consent often applies to "other" people or "for later". In order to avoid disappointment in practical projects, a consistent focus on the target group is crucial.

Keywords: Ambient Assisted Living, user acceptance, user perspective, household services.

1 Introduction

The aim of many research projects in the field of Ambient Assisted Living (AAL) is to facilitate independent living in old age with the help of intelligent technology. The portfolio of these projects often comprise access to the Internet, control of home automation devices, the possibility to order services through specifically developed electronic platforms, which also might be used to facilitate contact with the landlord or to check and submit consumption data. The diffusion process of these technologies, however, progresses only slowly in households of the elderly. Many user tests are still carried out only in a small number under artificial conditions (e.g. Living Labs), which offer no real practical experience in daily life. In only a small number of projects AAL technologies are employed in a larger amount of dwellings of elder people over a longer period of time (e.g. the Smart Living Manager at several locations in Germany [1]). Moreover, we only know little about how frequently services are ordered via an electronic platform.

The Department of Urban Sociology at the University of Kaiserslautern has been researching on the acceptance of AAL technology for quite a long time in different projects[1] [2, 3]. In the context of these projects a number of written surveys and interviews with users, non-users and potential users were conducted (s. table 1). In the following, some the results of the research on the acceptance to use innovative technologies at home and order services via an electronic platform are presented.

Table 1. Surveys on AAL technology and services by the Department of Urban Sociology, University of Kaiserslautern

Aug.-Sept. 2007	written survey	405 tenants of the GBS Speyer
Oct. 2009	face-to-face interviews	21 tenants of the BauAG Kaiserslautern
March 2011	face-to-face interviews	11 tenants of the BauAG Kaiserslautern
April-May 2011	face-to-face interviews	8 participants of the TSA-Project
May-July 2011	written survey	410 tenants of the GBS Speyer

2 Acceptance to Use New Technologies at Home

As concrete benefits of AAL technology in everyday life are often unknown, elderly people hesitate to install the innovative technology, e.g. a tablet PC for home automation and sensors. Generally, there are no experiences, especially no experiences of relatives, acquaintances or neighbors in the usage of such technologies, which play an important role when it comes to the decision making to acquire new things. Additionally, the cost-benefit ratio is difficult to assess.

The acceptance to use AAL technology in principle and the willingness to pay for the installation of certain devices in the field of home automation and health technology were - besides other aspects - the subject of two tenant surveys carried out in 2007 and 2011.

2.1 Acceptance to Use Technologies in Speyer, Germany

In two postal surveys tenants of the Gemeinnützige Baugenossenschaft Speyer eG (GBS), a cooperative housing society in Speyer, Rhineland-Palatinate, Germany, were

[1] In this context, research was carried out as part of the BMBF-funded project "TSA – Technisch-Soziales Assistenzsystem für Komfort, Sicherheit, Gesundheit und Kommunikation im innerstädtischen Quartier“ („Technical and Social System for Comfort, Safety, Health and Communication in urban Areas") (08/2010 to 07/2013) and the project "Assisted Living – Wohnen mit Zukunft“ („Living the Future") (04/2006 to 03/2009), funded by the Ministry of Finance of Rhineland-Palatinate and by the participating housing companies GSG Neuwied, GBS Speyer and BAU-AG Kaiserslautern.

asked[2] about the acceptance to use AAL-technologies ("Which technical devices might currently be useful in your everyday life? Which of the following devices would you use from the list?"). The list in 2011 also included an emergency detection and alarm generation based on unexpected inactivity, developed by the Institute of Automatic Control, University Kaiserslautern [4, 5]. Figure 1 shows that the stated acceptance to use some of the applications is very high.

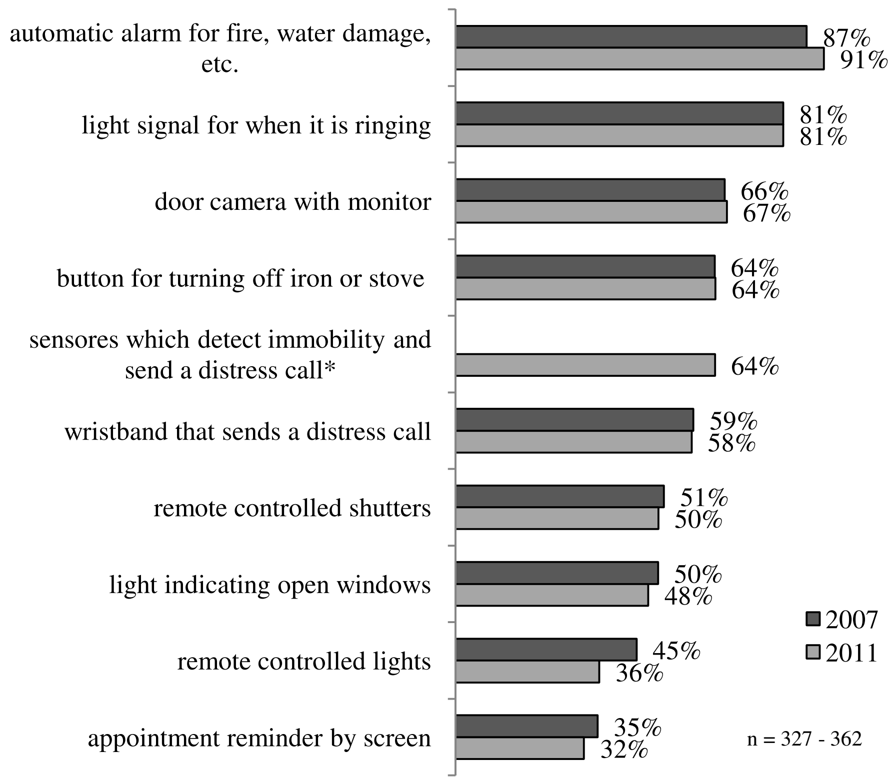

Fig. 1. Acceptance to use AAL technology in 2007 and 2011. *only asked in 2011

91% of all respondents in 2011 stated, that they would use an automatic alarm for fire, water damage, burglary or a gas leak. In 2011 we found an even greater acceptance for using than four years ago. Maybe this is because the landlord equipped the complete housing stock with smoke detectors in the previous years. More than half of the respondents are in favor for the following devices: a light signal for when it is ringing for the hard of hearing, a door camera with a monitor, sensors which

[2] The two written surveys of tenant households of the GBS were carried out as part of the projects mentioned in footnote 1. With 405 returned questionnaires in 2007 and 410 in 2011 a good response rate of 26% and 27% was achieved. Since both surveys were carried out with the same residents, a comparison of the results is possible.

recognize immobility and automatically send an emergency call for help (emergency detection based on inactivity), the possibility to turn off the iron or stove at the push of a button and a wristband that sends a distress call. All these devices primarily refer to residential security. The less accepted devices include: shutters with a remote control, a signal lamp which displays open windows, lights with a remote control and an appointment reminder by screen. Some of these devices are already widespread in private homes. Maybe some of these applications are seen as a convenience rather than as absolute necessary by many respondents. The difference of nine percent points in 2011 compared to 2007 regarding the remote controlled lights cannot be explained.

Elderly people are the target group in many projects in the field of home automation and health technology. Therefore, the data on the acceptance to use these devices was also analyzed with regard to the age of the respondents (exemplified by the results of 2011). In three cases among the ten devices which were part of the survey significant differences between younger respondents (up to 59 years) and those aged 60 and older could be identified (Fig. 2).

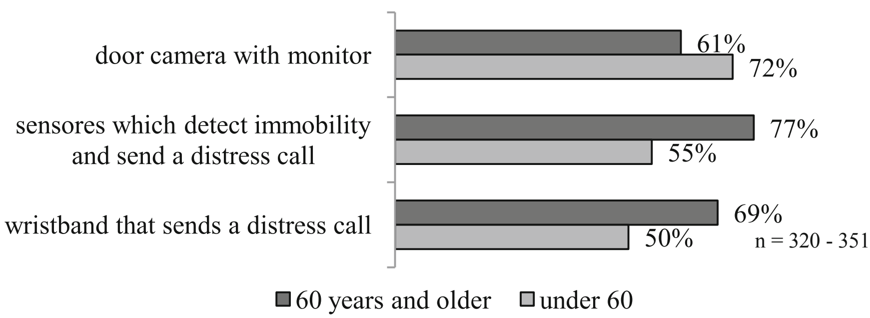

Fig. 2. Acceptance to use to use selected AAL devices (age comparison 2011)

A wristband, which measures movements and body temperature and automatically sends a distress call in case of emergency, is more popular by the older respondents (+19 percentage points). There is even a greater difference looking at the sensors in the apartment which recognize the immobility and automatically send a call for help in case of emergency (+22 percentage points). On the other hand, older respondents find a door camera less useful (-11 percentage points). The lack of experience of older people in dealing with monitors can be the cause for this difference in acceptance. Looking at these results, especially devices from the fields of safety and health seem to be important to the respondents, rather than those from the field of comfort. Among older respondents, this is even more pronounced.

Similar experience was gained in the project "Assisted Living – Wohnen mit Zukunft" in Kaiserslautern [2, 6], within which 20 apartments were equipped with AAL-technology in late 2007. In this project, health and safety aspects also played an important role leading to a positive attitude towards the smart home technology. However, in comparison to the written survey for potential use in Speyer there are differences in the order of functions in actual use. While in spring of 2011 the door camera was favored in usage, the button for turning off the iron or stove was rarely used. In contrast, the remote-controlled shutters were used more frequently than the results of the written survey show. Surprisingly, the remote controlled lights and the signal lamp for displaying open windows are not favored in actual use at all. Contrary to the results of the written survey, the door camera which shows a picture of a person ringing at the front door bell is widely used. It provides security, because unwanted people do not even get to the apartment door. Also, the ambient emergency detection based on inactivity is favored because an undetected downfall may cause severe effects. Surveillance fears are mentioned in public debate, but for the interviewed tenants this is less relevant, as the benefit of the technical devices is ranked higher.

In a survey amongst the tenants prior to the installation of ambient emergency detection system in October 2009 a total of 17 of the 18 respondents stated that this assistance system is regarded as helpful. Eight of the proponents, including two married couples, restrict, however, that this feature is not beneficial for themselves, but rather for others - older people or people living alone [7]. Comfort features such as turning off lights and remote controlling the shutters are often used, but are hardly relevant for the evaluation of the AAL system. These tools help to feel comfortable, but are not seen as an absolute necessity, even if the tenants do not want to miss them, now that they have got used to them. Acceptance builds up and changes with time.

2.2 Willingness to Pay for New Technologies

Following the question about the willingness to use the technical devices in principal, the tenants of the written survey in Speyer were asked to provide information on whether they would be willing to pay for the installation costs (once) or for the usage (monthly). In 2011 more than half of respondents (57%) indicated to be willing to pay for the installation of these devices, but only a third (33%) would pay for the usage once a month. While the willingness to cover the installation costs of the technology is similar between older and younger respondents, it differs significantly in the willingness to pay a monthly usage fee. 40% of the 60-year-olds and older are willing to pay each month for the usage, but only 28% of the younger respondents. In 2007 49% of all respondents stated to pay for the installation and 35% for the usage. Significant differences between ages could not be determined at that time. The willingness to pay for the installation is eight percentage points higher in 2011 than in 2007.

3 Usage and Acceptance to Use Services

Part of the TSA-project is – in addition to technical support at home by applications in the field of safety, comfort and health as well as communication with other participants, family members and people from the neighborhood – that the tenants get the opportunity to order household services and services from the local district with the help of the technology. For this purpose, a touch screen monitor will be equipped with special software at a later point in time. To assess the needs of such offers, the tenants of the written survey of 2011 and all persons participating in the TSA-project were asked about their acceptance to use and current use of various services.

3.1 Acceptance to Use Services (Written Survey)

All persons participating in the written survey, aged 60 years and older (n = 171), were given a list with a total of 24 different services. They were asked to indicate whether they use these services at present, would like to use them currently, maybe in the future or for sure not (see Figure 3). As this set of questions was not part of the first survey in 2007, no comparisons can be drawn.

The services that are currently used by more than ten percent of the respondents, are: sweeping the sidewalk (including snow clearing and gritting, this service is provided by the GBS; 25%), home visit by a doctor (17%), pharmacy services (supply of drugs, 15%), foot care at home (13%), delivery of groceries (such as beverage cases or frozen food; 13%), hairdresser service at home (12%), and taking care of the apartment in case of absence (12%). The latter, most likely, primarily refers to neighborly help. At the lower end there are advices for daily living (no mentions), visiting service (1%), and ambulatory care services (2%). An in-house emergency call system is currently used by six percent of the respondents.

For the TSA-project information about services that are not yet used, but which are currently desired, is of particular importance ("would like to currently use"). However, only a few respondents mentioned a desire for these services. At this point, most frequently home visit by a doctor (a total of n=16) and repair services (e.g. of electrical equipment) (a total of n=17) were mentioned. Between two and 14 respondents wish for the other services. The unspecific desire to use the services at a later time is significantly higher ("would like to use maybe in the future"). Over half of the services listed received an approval of 50% or more.

The least popular services ("wouldn't use at all") were pizza delivery and meals from restaurants / catering (61%), advices for daily living (61%), grave maintenance (57%), taking care of the apartment in case of absence (54%) and ironing (52%). On the opposite side of this negative ranking, as also evident from the sum of the current and future acceptance to use, are the most popular services: home visit by a doctor (4%), in-house emergency call system (9%), ambulatory care services (10%) and pharmacy services (16%). It is noteworthy that all four services with the lowest rejection – and therefore with the greatest approval – fall into the realm of the health sector.

The majority of respondents have indicated to use one or more of the services listed at present, or would like to use them currently or in the future - more than half of the respondents would even use 13 (of 24) or more services. However, this does not mean that these services would actually be used. It also remains unclear which requirements must be met to match the needs properly. Due to the already very extensive questionnaire in the survey the tenants were not asked about the willingness to pay for the use of the offers. Also data was not collected, about the circumstances that would lead to a future use of services.

To obtain further information about the acceptance to use the services, these issues were an integral part of interviews with the participants of the TSA-project.

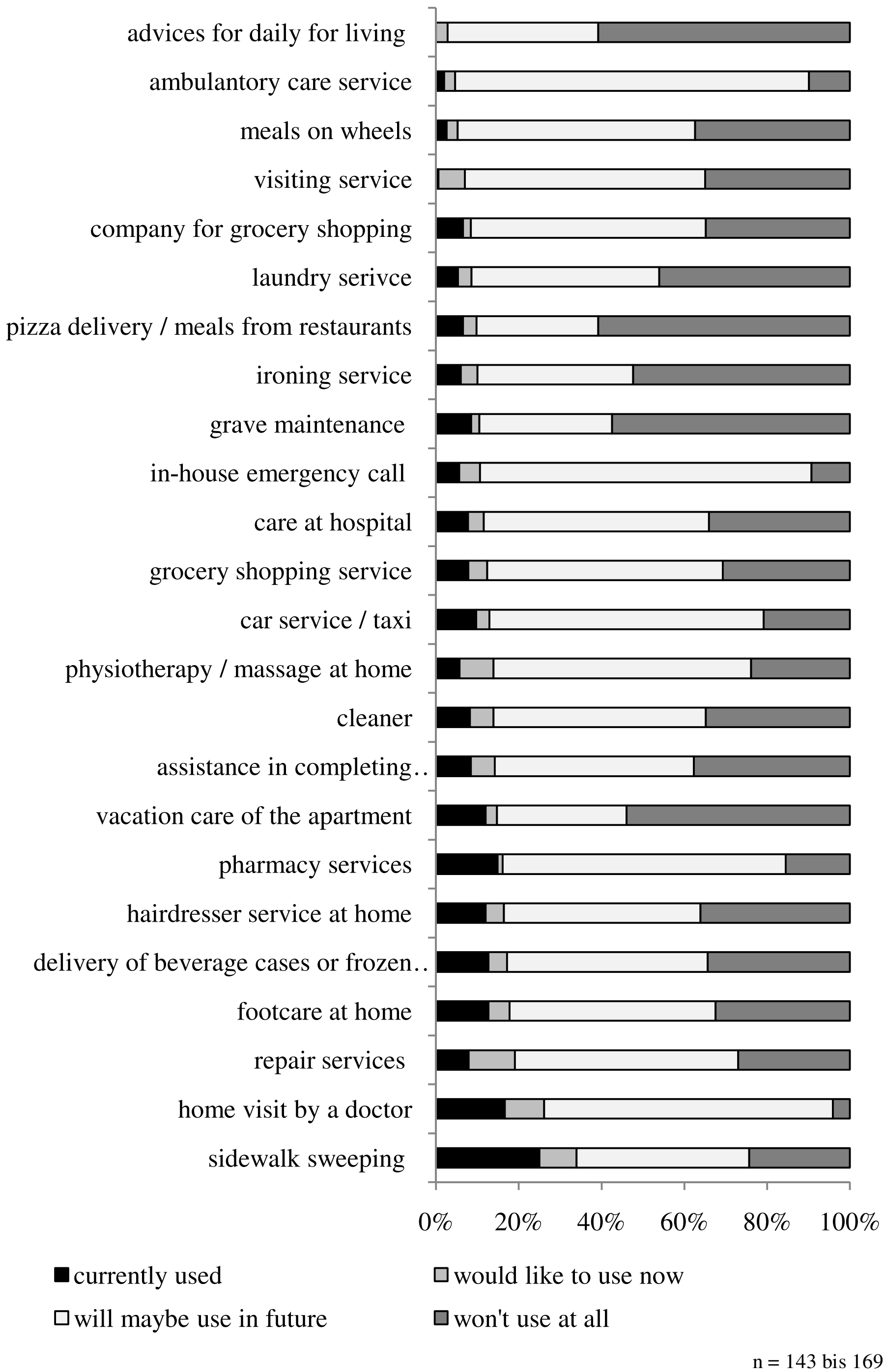

Fig. 3. Acceptance of services

3.2 Acceptance to Use Services (Oral Interviews)

In the spring of 2011 oral interviews were conducted with the first seven participating households[3] of the TSA-project in the framework of the sociological research. During that time, the households already had consented to participate in the project, but the installation of the devices took place only a few weeks after the survey. The interviews were designed as open, narrative interviews. The aim of the survey was to determine attitudes and needs of services.

To get a broad picture of the various domestic support services, the interview guide was supported by cards. On each of 24 cards a single service was written (which were also part of the written survey). They cards were spread out in front of the participants and explained briefly. Afterwards, the participants were asked to comment on the offers and to indicate whether they use these services at present or would like to use one or more of them - regardless of the participation in the TSA-project. Not every participant commented all the services.

A cleaner, home visit by a doctor or a patient care service and hairdressing services at home are accepted by all seven interviewees who answer this question. This means, that they would make use of those services in case of need or already use them at present. Pharmacy services, at home foot care, physical therapy at home, and meals on wheels are also widely accepted (by six people).

Interviewer[4]: Physiotherapy or massage at your home?
Woman: Yes, yes. if necessary, that would be very good.

Interviewer: Did ever an ambulatory care service or a doctor come to your home?
Woman: Yes, to my husband, he was here once.
Man: Yes, he came to me once.
Interviewer: Would you like to have this also for later?
Woman: Yes, that's why we have chosen a family doctor, who comes into the homes, because you never know if you need him.

Interestingly, the interviewees also hardly commented on both services which were objected for the most part in the written survey (pizza service and meals from restaurants / catering as well as advices for daily living). Other rather unpopular services are housekeeping activities such as shopping assistance, laundry or ironing service, because the (physical) effort this is regarded as rather low:

Interviewer: A laundry service?
Woman: Yes, but I think the washing machine, you can manage that yourself. I cannot imagine that quite well.

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3 The survey was conducted using semi-structured interviews and an additional short standardized questionnaire. Six tenants of the GBS and two tenants of the German Red Cross (DRK Kreisverband Kaiserslautern) were interviewed at that time. The five women and three men are between 60 and 86 years old, there is one couple. All participants have health problems, but three stated to feel "fit" or "very well" at the time of the survey. Two have experienced several downfalls and do not leave the apartment alone due to their health status.

4 Own translation of the interviews from German.

Interviewer: An ironing service?
Man: I don't need that. I still can do that by myself.

Interviewer: A shopping service, someone who goes grocery shopping for you?
Man: I prefer going shopping by myself, to see what I buy. Yet it works.

Overall, it is found that the interviewees – as well as the respondents of the written questionnaire – have a positive attitude towards the proposed service offerings, and would make use of professional help, but only in case the support cannot be covered by family members or other acquaintances. However, most interviewees emphasized that they would only make use of the services if there is an urgent need.

Interviewer: Would you like to have assistance in everyday life?
Man: Well, I have to see if I can get assistance maybe. A cleaning lady or so. So that you get aid, if you cannot do it by yourself anymore.
Interviewer: Would you like to have that now or later?
Man: I will wait a bit. For as long as you still can do something by yourself… The exercise is good for me (...)

It also becomes clear, that the number of services which are desired for a future use is significantly higher than the number for the currently desired ones. The interviewees want to keep house independently as long as possible, even though it become hard for them. Furthermore, they turn down outside help in order to stay "busy" or feel "fit". This especially becomes apparent in one case, in which a participant already gets support at home (e.g. cleaner), she insists to clean the floor despite her significant health problems.

Woman: (...) But now, I have to exercise, you know. Last week I even cleaned the bathroom. You know, I have crutches, and I clean with the crutch ... [shows how she handles it]
Interviewer: With the cloth on the crutch?
Woman: That's fine. I did the kitchen and over there.
Daughter: You don't have to do that.
Woman: But you know, if I just sit or lie in bed, I cannot do so. Then I will never get on my feet again (…).

The low level of acceptance to actually make use of support can also be illustrated by the use of a conventional in-house emergency call system: A participant has such an emergency device (wristband), which, however, according to her son she does not wear regularly, even though she already had a severe downfall and was able to successfully call for help using the wristband. Another respondent rejected the emergency call system even when her son had already ordered one after she fell and had to "crawl" to the phone to get help. She rather relies on her neighbors.

In many interviews it became apparent that support from family members is preferred rather than professional help. Furthermore, financial reasons also play a crucial role in the actual acceptance of support services.

3.3 Ordering Services through a Touch Screen

One aim of the TSA-project is to enable the participants to order domestic support services and other additional services from their district with the help of a touch screen PC named “PAUL” (Personal Assistive Unit for Living). The requests for these services are to be posted by the participants via PAUL’s touch screen (development by CIBEK) and will then be forwarded to a concierge (a nearby retirement home). The request can also be sent directly to the concierge via videophone. The concierge will then forward the request to a service provider, which preferably is located close to the participants dwelling.

The possibility to "order services via PAUL" was addressed twice in the interviews; once at the assessment of the technical devices and once when the participants were asked to value the services in general. A total of six of the eight interviewees value this function of PAUL positively, and in two cases is not clear whether the ordering process (ordering via touch screen) or the services as such were rated. One interviewee highlights, that no more phone numbers have to be memorized:

Woman: That's great, that's great. If this situation arises that you need this assistance and that it would be possible, that would be an enormous relief. Then I do not need to remember phone numbers anymore (...) But this is a very wonderful situation now and in combination with this new technology, I really feel cared for.

Four persons state, that they would only make use of ordering services via PAUL if there is an urgent need.

Interviewer: Could you, nonetheless, imagine ordering those services via PAUL in future?
Woman: Yes. I could imagine that. It's hard for me now because I'm still fairly mobile. You always think it stays this way. You know that it does not stay this way. (...) No, but if I needed help I can imagine to use it.

The participating tenants in the project in Kaiserslautern also were asked about their acceptance on ordering services via PAUL at a tenant meeting. The feedback was clear: they would not use (commercial) services – although this group has long experience in the use of PAUL. Social cohesion in the household plays a larger role. A cleaner will be accepted only on recommendation, for example. The procurement of services by a neutral server is not considered by the tenants.

5 Summary

The results of quantitative studies show a relatively high level of acceptance to use AAL-technology at home from the perspective of potential users, especially in the fields of safety and health. In addition, the increased willingness to pay for the installation of such devices might indicate that this technology gets diffused more progressively in senior households. These positive results confirm other studies on the acceptance of AAL technology [8, 9]. However, a market potential for the tested techniques may not necessarily derive from the statements on the acceptance of use. Meyer et al. noted that seniors are often very reluctant in the use of technology, even if they have very positive attitudes [10]. They often mean the need of the devices for “others”, while they would not use them in their own home.

In our practical example in Kaiserslautern we could show that comfort features, such as remote controlled shutters, contribute to the well-being, but are seen as not very necessary, even if the interviewed tenants do not want to miss the features after a period of habituation. Hence, acceptance builds up only with time.

As well as AAL-technology, although supported in principle, concepts that include a comprehensive range of services have to be considered critically in regard to the acceptance in practice. This applies especially when these services are to be ordered with the help of AAL-technology. Currently, there are - in addition to TSA - some other AAL projects in Germany (e.g., Service4home, SELBST, WohnSelbst, see [11], which envisage the procurement of services via technical devices (TV, monitor, digital pen). Our surveys have shown that these functions play no role yet, because the elderly require a bond of trust before they accept services. Whether and to what extent this can be proved or disproved in the longer term, we hope to show with further research as part of the TSA-project.

If there are difficulties with user acceptance of AAL-products, it may be due to the accentuation of features which are not in the foreground of elderly people. Other problems of enforcement arise from a reluctance to use new technology because it is tainted with the image of being complicated. The English term "Ambient Assisted Living" does not contribute to a reduction of fear of contact. If the address is not aligned to the target group, the benefit for everyday life is not demonstrated convincingly and a certain handling is not put across, AAL technology for the elderly is very difficult to enforce.

The technical development towards touch screens, which may be specially designed for the elderly, should help eliminate the disadvantage of being labeled as too complicated. And with the help of tablet PCs with a touch pad (such as the iPad from Apple), which are considered chic and modern, such a device is less likely to be considered to be a product for seniors and therefore to be stigmatizing.

A further advantage may be the new wireless technology which allows an installation without constructional changes. Reconstruction measures for cabling are associated with noise and dirt and are not desired and were a previous obstacle to a broader acceptance. Wireless switches can be attached to basically any desired position, as long as the signals reach the receiver. The sensors only have to be connected to an electrical connection, in case they do not get enough sunlight to power solar cells.

Even if AAL technology is used seldom by now, the obstacles seem surmountable.

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Part V:
Platforms

Taxonomy-Based Assessment of Personal Health Monitoring in Ambient Assisted Living

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Abstract. Introducing Ambient Assistive Living (AAL) systems onto the market is a challenge. An interdisciplinary evaluation of system design should be integrated into the development process at an early stage. A toolkit to facilitate the evaluation process for developers as well as stakeholders and policy makers is presented. This toolkit includes a taxonomy that outlines the technological traits of personal health monitoring (PHM) and application fields of PHM within the AAL domain. The taxonomy can be used either within the toolkit, or as a stand-alone tool; its aim is to achieve a better mutual understanding of the concepts used in the dynamic field of AAL.

1 Introduction

The fast-paced development of care related health monitoring solutions that are designed for personal use stalled at the transition of prototypic systems into mass market systems. The reasons for this phenomenon have been claimed to be legal and economical as well as ethical issues [1].

The phenomenon of decreasing interest in emerging technologies is not unheard of. In Gartner's hype cycles [2], this phase is labeled as the "Trough of Disillusionment". It is vital for a successful market introduction of an emerging technology to overcome this phase and reach the "Plateau of Productivity". For this purpose, the development of the best possible technical solution is not sufficient. The users' needs have to be considered and the acceptance of the product with all involved stakeholders has to be ensured, as well. This requires an interdisciplinary assessment of the legal, ethical, psycho-social, and economic implications of the new system at an early stage [3].

While an early integration of experts from these disciplines will help to prevent unpleasant surprises, it will also bring up new challenges, most of which are caused by communication difficulties [4]. It is therefore necessary to develop a mutual understanding and a common language. The development of a mutual understanding can be supported by schemes that unambiguously define the concepts of the respective domain. In an emerging field where a lot of the developments are made in independent projects with very different focus, it is most suitable to introduce a flexible classification scheme that supports new development streams, and thus builds groups based on empirical analysis rather than on pre-defined characteristics. All of these requirements are met by taxonomies [5]. The main purpose of a taxonomy is to group items and to connect them to each other. Thus, a taxonomy is a classification of items within a domain, similar to a typology. The main difference is that taxonomies build their groups a posteriori, i.e. based on empirical analysis instead of on pre-defined characteristics. This procedure is most suitable when dealing with unexplored phenomena. The flexibility of post-analysis creation of groups allows the integration of previously unrecognized traits as distinctive attributes. It is unlikely that all pre-defined categories of a typology are exhaustive and mutually exclusive, if the population is not established [6]. A prominent example of taxonomies is the Linnean Taxonomy in biology. In zoology, the four steps to create a taxonomy are: (a) sorting individuals into phena or ‘body types’ and then into demes (subsets, or local populations), (b) assigning demes to species (populations), (c) grouping populations into higher taxa, and (d) ranking taxa in hierarchical order [7].

2 Foundations and Methods

To describe the development of the Personal Health Monitoring (PHM) Taxonomy, some aspects of PHM in Ambient Assisted Living (AAL) need to be outlined first.

2.1 Personal Health Monitoring in Ambient Assistive Living Technologies

Companies that currently are developing personal health monitoring (PHM) devices stem from two markets: Consumer electronics and medical devices. This is due to the two main target markets: The “motivated healthy” and the “chronically ill” [8]. The term “motivated healthy” describes persons who take great interest in their well-being and use PHM products as a life-style device. The special interest group for “Quantified Self” (quantifiedself.com), a group of enthusiasts who discuss personal measurement technologies, describe this attitude as “self-knowledge through numbers” [9].

The medical devices manufacturers offer telemedicine systems for treatment-related applications. The main aim of these systems is professional health care delivery through telematics or telemonitoring with a well-defined patient-carer relationship.

These devices are then also marketed for general use by private persons. The main target group for these systems are individuals with a medical condition and an interest in monitoring their health status, e.g. people with a known risk or a chronic disease – the so-called “chronically ill”.

The different perspectives of vendors and users on PHM devices are reflected in the primary functions and design of the systems. There is, however, a third large group of potential users that attracts the vendor’s attention. This group, which is potentially even larger than the other two groups, consists of individuals interested in monitoring their health status in order to maintain their lifestyle despite deteriorating health. Systems that are designed for this group form a sub-set of ambient assisted living technologies. These systems enable users to live an independent life despite a medical condition that otherwise would result in partial or complete dependency on care providers, or at least in a severe decrease in quality of life.

The potential users of AAL or PHM technologies are professional carers, supporting relatives and lay carers, elderlies, persons with a high potential risk, and the motivated healthy. These groups of people have a different motivation and, accordingly, a different willingness to invest in AAL devices [10]. In anticipation of a rising demand in professional care that accompanies the demographic change, professional carers use AAL technology to increase their efficiency and to tap new customer markets [11]. Lay carers use AAL to facilitate their care-giving. Moreover, they can find relief of the demanding expectations of their relatives with respect to availability and responsibility. The motivated healthy seek information about their own health and use AAL technology in lifestyle gadgets.

In spite of the different perspectives on PHM technologies, the ethical, legal and psycho-social challenges often are similar.

2.2 Development of the PHM Taxonomy

The PHM Taxonomy that is presented in this paper was developed within the PHM-Ethics project, which is an EU FP 7 project. PHM-Ethics is designed to conduct interdisciplinary research on the relationship between ethics, law, and psychosocial as well as medical sciences in personal health monitoring [12].

The aim of the project is to develop a toolkit for the assessment und evaluation of risks, potentials, and implications of PHM technologies. This toolkit consists of several modules: a dependencies map that analyzes the interdependencies between stakeholders within the PHM domain, a legal module that sums up the different national legislation of the EU member states and the EU-wide legislation on telemedicine and personal health monitoring, an ethical and a psycho-social assessment module. The taxonomy provides the basis for interdisciplinary collaboration within the project. It categorizes and describes the different trends and developments within the field of PHM, thus building the ground for a mutual understanding and a common language.

The taxonomy is based on an analysis of 85 reviews from the years 2000 through 2009. The reviews were retrieved with the search terms 'AAL and smart home' (13 reviews), 'telemonitoring' (45 reviews), 'personal health monitoring' (25 reviews), and 'pervasive health care' (1 review). The AAL and smart home reviews covered more than 70 systems, some of which may have been reviewed in more than one paper. Thus, the set of unique systems is probably much smaller, but the different perspectives of the reviewers may still deliver valuable information. Telemonitoring reviews mainly dealt with cardiac diseases, diabetes care, or home blood pressure monitoring, and cumulate to a total of 178 studies. Given the fact that most of the reviews were published within a rather short period of time (44 of 85 in 2007 through mid-2009), and mostly deal with one of only three fields of application, the number of unique PHM systems is most likely significantly smaller. The reviews on personal health monitoring include more than 100 studies, though the majority of them (almost 80 studies) are reviewed in one paper on prescription adherence [13].

The observed transition of the measurement setting from a clinical or doctor's office setting into a personal setting suggests grouping the systems in a traditional, application-based way ('application view') by relating the fields of application to the medical sub-domains. Further examination showed that this grouping is not consistent, because the lines drawn between the groups are blurry, which results in ambiguity. Multiple systems are used in several fields of applications and some fields of application solely rely on combinations of systems and deduce their specific readings from these combinations.

Another possibility would be to categorize the systems according to the way they measure health parameters: permanent monitoring vs. discrete measurement, active vs. passive or inferred measurement. Those categorization approaches also seem to be prone to bias. However, the taxonomy highlights technologies that are currently in use or will, in all probability, be used in the near future. Thus, an approach was chosen that is not subject to bias or arbitrary grouping of systems, but rather depends on the physical and technical method that leads to parameter readings. The 'technology view' extends the application view with details from a technical point of view. Linking technological features with implications derived from the application field combines the advantages of both approaches. Hence, both views are incorporated into the taxonomy

3 Components of the Taxonomy: Application and Technology Layer

The developed taxonomy organizes the aspects of PHM technologies into an application and a technology view. These views reflect the different implications that a technology might have with respect to the intended use. What seems appropriate in a professional setting within the scope of patient-physician relationship might not be appropriate in other relationships, for example between lay carers and the relatives they care for. On the other hand, certain technological features might have a higher impact on values like privacy – monitoring people's movements with cameras, for example, is perceived as more intrusive than monitoring them with motion detectors [14].

3.1 Application View

Assessing the impact of a technology is highly dependent on the intended use. Figure 1 shows the environments in which personal health monitoring systems can be integrated. They range from PHM in health care applications, which again are classified in a traditional medical perspective into preventive systems, treatment related systems, assistive systems, and rehabilitative systems. A second branch incorporates personal health monitoring devices for health related applications such as, for example, occupational health. The third branch incorporates applications in which PHM systems of whole population groups can be analyzed to infer public health related information.

The different fields of applications have an influence on technology assessment because of different legal and ethical settings, and a different impact on psycho-social issues. Systems that transfer data with remote systems, for example, require a sophisticated mechanism for the protection of data security and privacy. Furthermore, the user needs to trust the operator of the remote system to keep the data safe and prevent misuse. This is also reflected in the requirement to adhere to data protection and privacy laws. The questions on who owns the data, what data can be stored for how long, as well as opt-out mechanisms for monitoring systems, need to be reflected upon [15]. In some scenarios, the different legal regulations might even conflict with

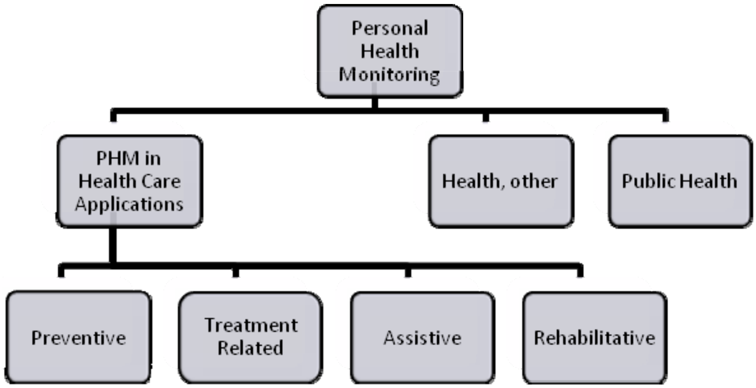

Fig. 1. Classification of application fields of PHM systems in a traditional medical perspective.

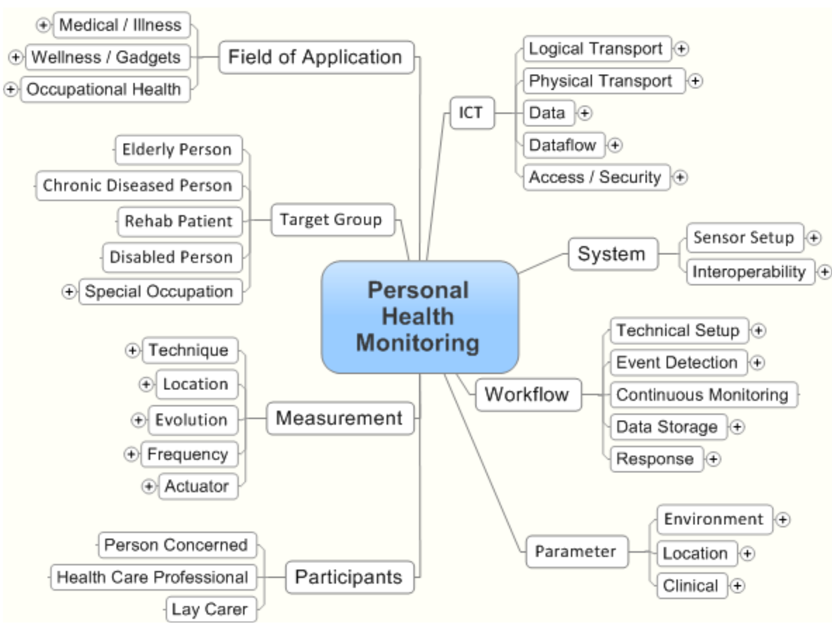

Fig. 2. Classification of socio-technical attributes of PHM systems in a hierarchical tree structure.

each other. If a diagnosis is based solely upon PHM systems, the user's right to delete data, for example, might stand in conflict with the doctor's obligation to store the patient's record. Inherent in the question whether or not a system may be used for medical decision making is the classification of said system as a medical device. This can result in obligatory clinical trials according to the Medical Devices Act. Systems designed for personal information are not as tightly regulated as systems for health professional use. This is not only valid for the design and data management processes, but also for the monitored parameters. Many values need to be appreciated within context, for example the need for privacy vs. safety and security in either a preventive fall detection system or a system to detect wandering in individuals with cognitive impairments. This is very similar to whether a system is perceived as incapacitation or empowerment. A system that might be perceived as incapacitation among healthy people might be perceived as empowering for chronically ill or physically handicapped people. These examples show that different applications require different mechanisms to protect the privacy, safety and security of the user. This also includes the protection against unauthorized use of a PHM.

3.2 Technology View

The technology view is a hierarchical tree which classifies the attributes of a PHM technology along nine main axes. These axes are "Information and communication technology", "System", "Workflow", "Measurement", "Participant", "Target Group", "Field of Application", and "Parameter". "Participant" and "Target Group" are included into the technological view because of their importance in socio-technical system analysis.

The levels further down the tree are classified into characteristic functional groups. On the lowest level (the leaf nodes), instances of PHM attributes of the preceding group are included. These instances feature the characteristics of all preceding groups up to the root node (the highest level node). The degree of detail (number of levels) is not limited, yet it is advisable to keep the number of levels as small as reasonable possible in order to maintain a concise view.

3.3 Validation of the Taxonomy

Taxonomies in terms of classification schemes are based on empirical analysis and are open to new items, thus they cannot be validated comprehensively. It is merely possible to verify the underlying rules used to classify the items. The verification process shown in figure 3 tests the stability of the taxonomy when "populating" the groups. The result of any two runs of the grouping process should be similar irrespective of the sequence in which the items are included, thus subsequent inclusion of new technologies is supported by the taxonomy's nature. Every item should belong to exactly one group. If an item does not belong to any group at all, then a new group may be created, as long as this new group does not violate the mutual exclusiveness. This is the case if a new item that is clearly within scope of the taxonomy does not fit into one of the existing groups. This mechanism identifies items that do not belong into the domain reflected by the taxonomy. The mechanism can be used to verify the taxonomy by including technologies that are related to PHM, but not within the scope of PHM. In the case of the PHM taxonomy, this could be a measuring device that is solely used for public health measures, like body heat measurement at airports that screen for potential SARS or avian flu infections [16].

The PHM taxonomy has been validated using six case scenarios that where provided by the PHM-Ethics project partners.

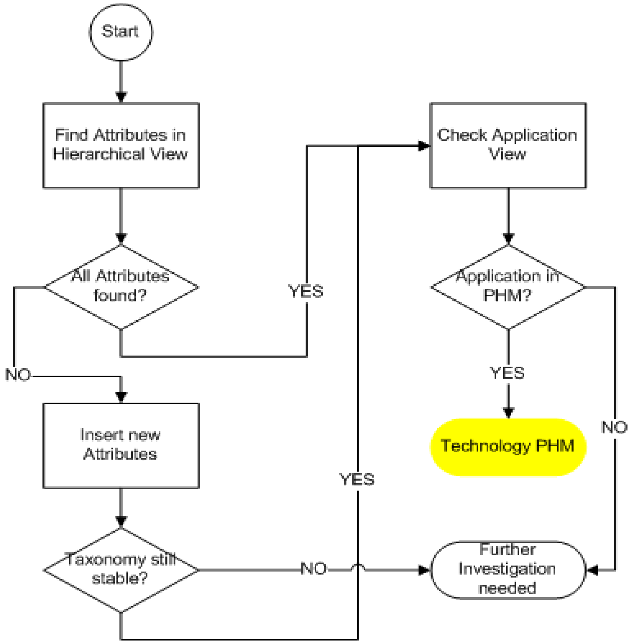

Fig. 3. Workflow for testing a new technology for inclusion into the PHM taxonomy

Additionally, the taxonomy was reviewed by experts during an international validation workshop. The taxonomy and the rules must be revised periodically to incorporate technological innovations as well as new fields of application.

3.4 Flexibility of the Taxonomy

The taxonomy can be expanded with other views in order to analyze further dimensions that have an impact on the technology. One example of such an expansion is the addition of the dimension "location" for the classification of privacy and data protection implications of AAL technologies. In this dimension, the technologies are grouped according to their installation location, as shown in figure 4.

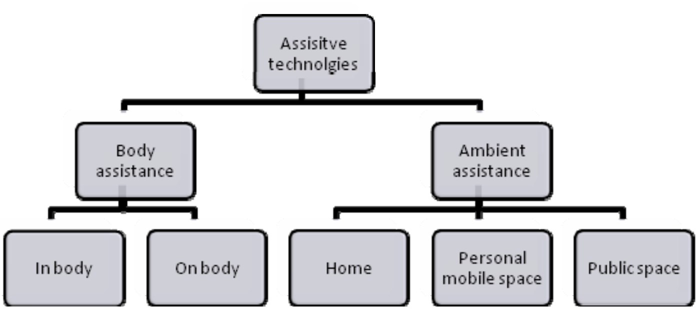

Fig. 4. Additional Dimension on Assistive Technologies. Assistive technologies are grouped according to their installation location.

The main axes in this dimension are “body assistance” and “ambient assistance”. Artifacts that are permanently fixed to the body or are implanted are grouped as “in body”, for example pacemakers or cochlear implants. Most artifacts in this group replace or enhance a body function. These items are separated by the “on body” artifacts because the user is bound to use the product once it is implanted. The person with implanted technology relies on the manufacturer’s support. In the “on body” group, the user can choose whether to use the product or not. The “ambient assisted” axis can be broken down into “personal domestic space”, “personal mobile space”, and “public space”. Technologies and services in these groups offer support by monitoring and analyzing a person’s surroundings, and reacting in an appropriate manner [17].

The setting in which the measurement and the analysis take place is vital for the assessment of privacy and data protection specifications. The rules that are used to group the artifacts are similar to the rules of the taxonomy development. The additional dimension in this example is not taxonomic because artifacts may be part of more than one group. The grouping by different specifications, however, would suggest that at least the implications show unique traits for each group.

4 Using the Taxonomy

The taxonomy has been used within PHM-Ethics as a tool for an interdisciplinary research project. It served its intended purpose as a framework to organize the technologic advancements and developments so that researchers from non-technical disciplines could abstract the implications of special technological features to higher levels and derive the consequences and challenges in their respective field. On the other hand, the taxonomy helped researchers from technical disciplines to understand the questions and concerns of their colleagues and link them with corresponding technological features. The taxonomy also proved to be a useful means to combine the different tools of the PHM-Ethics toolkit.

4.1 Taxonomy as Part of the PHM-Ethics Toolkit

Figure 5 shows the PHM-Ethics toolkit, which consists of five tools that can be linked with one another directly or indirectly. The taxonomy is part of the descriptive module together with a report on legal and ethical constraints of PHM devices with a European focus, and a dependencies map which “highlights dependencies between different disciplines, to fasten product development and to address relevant non-technical-issues of PHM at the same time. It focuses on the interrelationships of several stakeholders in PHM” [18].

The taxonomy has strong links to the dependencies map. Both tools form the basis for the identification of relevant characteristics for the other tools (psycho-social and ethical methodology as well as the legal framework) by describing characteristic attributes of PHM technology and their impact on depending actors and stakeholders.

The interactive ethical assessment module is one of the evaluative modules. It outlines the ethical values that need to be kept in mind when developing, implementing, or assessing a PHM device. Using the interactive assessment tool together with the

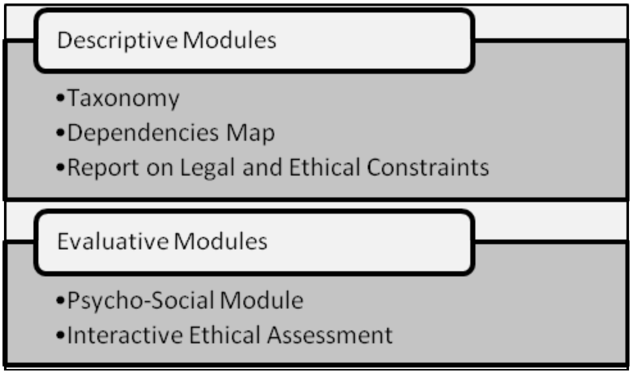

Fig. 5. Tools within the PHM-Ethics toolkit. There are three tools with descriptive perspective and two assessment tools. [18].

taxonomy and the dependencies map helps anticipatory exploration of the impact of PHM technologies on ethical values. The psycho-social module, also part of the assessment modules, focuses on potential benefits and risks of PHM devices from the user's point of view. Similar to the interactive ethical assessment tool, the psycho-social module can be combined with the taxonomy and the dependencies map to assess specific traits of a technology or to explore anticipated developments of innovative technologies.

Combining all tools of the PHM-Ethics toolkit produces a comprehensive framework for the reflection and evaluation of the risks and potentials of PHM technology.

4.2 Taxonomy as "Stand-Alone" Tool

The taxonomy may be used as a stand-alone tool to compare different technologies that fit the same purpose, for example to conduct a market analysis. This approach has proven to be useful for the market analysis of fall detection devices.

A vast variety of methods to detect falls has been identified, and even the definition of falls turned out to vary from system to system. A variety of possibilities to detect falls has been proposed by various developers for products in their concept stage as well as for marketable products.

Firstly, the technical view of the taxonomy facilitated the composition of relevant technological traits that need to be compared. Secondly, the application view suggested the grouping of applications into domains.

The taxonomy promoted the grouping of features along the hierarchical view. First, the parameters that are measured where analyzed. Most systems where identified to determine the posture of a person and detect a fall event using acceleration sensors. Few systems used pressure sensors, proximity sensors, thermo-optical sensors, or activity sensors. In a second step, the systems where classified as "body assistance" or "ambient assistance" systems (see figure 4). Characteristic traits for items in these groups where analyzed, for example advantages and disadvantages of portable in-body and on-body systems. Among these where for example the easy identification and determination of the location of the subject and mobility of the system, but also the likelihood of neglect to attach the devices on the body. Advantageous traits of the ambient assistive systems were found to be the low-key integration into the environment – thus reducing stigmatization, the advantage of assistance in situations where portable systems are often forgotten or simply not usable (e.g. at night or in the bathroom).

Finally, the intention of the system (e.g. fall detection versus fall prevention; as a stand-alone system or integrated into existing systems), and different definitions of detectable falls were arranged in the application view.

Thus, the link between different technical approaches and similar applications of fall detection systems was highlighted by combining the two views. Based on this, the relevant items for the market analysis could be identified and structured in an expedient manner to compare different approaches with similar, yet distinct scope in fall detection and prevention.

5 Discussion

The technology-driven development of Ambient Assisted Living systems has lead to a number of promising products. The market penetration, however, is still low. User acceptance and remuneration schemes are key factors for a successful market entry. As the health care market is highly regulated and as there is a multitude of stakeholders, innovative processes and socio-technical systems are not absorbed easily. Therefore, interdisciplinary evaluation is pivotal and should be considered in the development process as early as possible. This interdisciplinary research at an early stage can be supported by the PHM-Ethics toolkit.

The taxonomy of PHM technology is an integral part of this toolkit. It has been shown that interdisciplinary research can benefit from a structured representation of the different attributes of PHM technologies and applications. The PHM taxonomy goes beyond that. The taxonomy can be used to identify and compare technological approaches to specific tasks. It highlights interferences of applications as well as possible interoperations or interfaces between different systems. The issue of technological perspectives of interoperability is researched by several groups, e.g. STADIWAMI[1] or the Continua Health Alliance [19]. These efforts focus on hardware specifications and information exchange protocols. The taxonomy allows developers or integrators to go beyond the technical issues by identifying possibilities to expand the scope of a service by integrating appropriate new systems or collaboration possibilities, and by identifying psycho-social requirements. "The marriage of society and technology needs respect on both sides. To close the social-technical gap, technologists cannot stand on the sidelines: They must help. System designers must recognize accepted social concepts, like freedom, privacy, and democracy, that is, specify social requirements as they do technical ones. Translating social requirements into technical specifications is a daunting task […]" [3].

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[1] www.stadiwami.de

A structured analysis of technological attributes may help developers to identify requirements and pitfalls of a socio-technical system by including experts from the humanities into the development process at an early stage. Heeding the social requirements in the technical development process will most likely result in a higher user acceptance of the product. The integration of non-technological experts can be facilitated by the taxonomy's function as a basis for a mutual understanding and a common language, as the successful use of the taxonomy within the PHM-Ethics project has shown.

The taxonomy also proved to be useful for comparing technological traits of similar systems, or systems designed for a similar purpose. Using the taxonomy as part of the PHM-Ethics toolkit may allow policy makers to reflect on the impact of the technology and the necessity to change their policies accordingly. It may also allow other stakeholders to assess the psycho-social and ethical impact of the technology by using the respective assessment modules and linking the outcome to the technological traits in question.

The open design of the taxonomy will allow the integration of innovative features into the assessment and might identify requirements that, so far, lack a technological solution. One of the requirements that is reasonably foreseeable is the flexibility of AAL solutions. Members of the group of the motivated healthy may sooner or later develop a chronic medical condition, and therefore need a more elaborate telemedic system with incorporated services instead of a pure monitoring device. The transition from 'motivated healthy' to 'chronic ill' via the 'at risk' stage calls for systems that adapt to the users' needs. The taxonomy, however, is intended to be used by stakeholders, integrators, developers, and policy makers rather than consumers. Users will nevertheless need to know which systems will extend or replace their current devices and which services will be offered in the background. Nevertheless a "consumer version" of the taxonomy is not yet planned. This is greatly due to the fact that a taxonomy cannot be ultimately verified. Yet, the proposed taxonomy is designed in a flexible and adaptive way to cater for the drive of technology driven development. Several approaches to foster the development and the interoperability of ambient assisted living systems do exist like the "universAAL" platform [20] or the "AALiance" [21]. The PHM-Ethics toolkit expands these projects with a social sciences perspective on personal health monitoring systems. The taxonomy, as part of the PHM-Ethics toolkit, is the key element for a bi-directional knowledge transfer.

The taxonomy will need continuous maintenance and revisioning.

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Data Stream Management in the AAL: Universal and Flexible Preprocessing of Continuous Sensor Data

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Abstract. Continuous and potentially infinite sequences of data—so-called data streams—are processed in many applications of Ambient Assisted Living (AAL). The preprocessing of such high frequent data is normally done by fixed code or hard wired hardware. This leads on the one hand to an inflexible and extensive to change processing and on the other hand to very specialized solutions. Like databases data stream management systems (DSMS) offer a universal processing of data, but are designed for highly frequent and potentially infinite data streams. Thus, DSMS are an alternative approach for processing sensor data. Therefore, this paper shows how DSMS can be used in the AAL for an universal and flexible preprocessing of sensor data. For this, DSMS and its features are introduced and we show which advantages over existing solutions a DSMS can offer for future researches in AAL.

1 Introduction

The Ambient Assisted Living (AAL) explores various methods and concepts that aim to enhance the daily living by technology, which should be unobtrusive and competitive. Normally, such systems analyze different sensor data in order to gain contextual knowledge about the home and its occupant. e.g., a motion sensor can be used to detect the current activity or the current location of a person (see e.g. [24] [17]). This contextual knowledge can be used to interpret the current situation, which afterwards invokes an appropriate operation. A person who lies motionless on a ground in the kitchen can be interpreted as an unconscious person, who needs help. Therefore the system calls the rescue service and, e.g., turns off the stove. A fundamental component of such systems is the processing of sensor data, which are continuously analyzed to get an exact model of the environment—the so-called context model—as possible. To improve the accuracy of the context model, there are two possible approaches:

More Sensors: By using more than one sensor, it is possible to use more kinds of measurement types as well. Furthermore, a sensor is mostly restricted to a limited space. Thus, one sensor can detect that a person is somewhere in the kitchen and another sensor can detect that the person is walking. Due to the fact that applications get more complex, if they use a lot of different sensors, more and more middlewares are developed to combine various sensors and applications and sometimes to offer a common context model. This approach often uses component-based or service-oriented architectures, so that the system is also flexible and scalable.

Higher Frequency: A more frequent measurement by a sensor has two advantages. For the one hand states can be detected that normally would be hidden between two measurements. On the other hand measured errors can be detected earlier and cleared out, because the weighting of one value is smaller. To allow higher frequencies and more accurate values, a preprocessing is often done. This is mostly implemented directly into the sensor or into an interface that lies before a middleware, because the central application (e.g. the middleware) cannot handle the high rate or the huge amount of data in the majority of cases. Therefore, in most actual discussions about such central applications, it is assumed that a sensor will only generate one value per second. Thus, it is supposed that aggregations and filtering is done by the sensors on the raw data level.

Due to the fact that the outsourcing of the processing is sensor specific, a fusion is not possible on the raw data level, so that it has to be done by the central application (the middleware). Thus, the advantage of an information gain from earlier fusion of fine-grained data is lost [15]. Furthermore, the outsourcing of same processing-steps into different sensors produces redundant implementations. And if two applications want to use the same sensors, they have to accept combined or filtered data from the sensor or each application has to implement its own preprocessing. A combined approach for handling several sensors is to push all raw data into a database in the middleware. Afterwards, the database can be used to join, aggregate or filter the raw data. For this, the declarative query language SQL is a useful abstraction layer, so that more than one application can use the same data. But, assume that there are 10 sensors and each sensor produces 10 values per second, then the database has to save 100 values per second and about 9 million values a day. Therefore, the database would be grow very fast which makes it unfeasible for a long-term usage. In addition, a huge database size would be negative for the performance, because needed operations or time for searching grows too. Thus, time-critical applications cannot react in accurately time, e.g. if there is an accident, because the data processing takes too long. Even if no more relevant data is periodically deleted, this would also use resources and therefore negative for the database performance.

Therefore, in this contribution we want to introduce another approach that is possible by the use of data stream management systems (DSMS). DSMS are comparable to database management systems (DBMS), as the system is universally applicable and it is possible to use a query (e.g. like SQL) that is executed by an query processing. The fundamental difference is, that DSMS have continuous running queries that are durably installed in the system, so that arriving data can be directly filtered, joined or aggregated. For that processing a DSMS uses constant memory, considers a correct semantic and deterministic execution and optimizes the queries if possible (see [2] [1] [20] e.g.). Thus, a DSMS provides an ideal opportunity to centrally join multiple sensors and still allows high frequencies. In addition, they have also a flexible query processing, which is often the constitutive reason why most applications using a database. This problem can be often found in the AAL. Thus, this contribution shows what DSMS can provide and how it can be used in the context of AAL as a base technology or as an extension of existing systems. For this, DSMS and their most important characteristics are explained in section 2. Section 3 illustrates some key concepts of DSMS and how they are a benefit for AAL. Some useful extensions for AAL are introduced in section 4 and section 5 shows possible architectures for a DSMS in AAL and is completed by an example in section 6. Afterwards related work is shown in section 7 while section 8 concludes this contribution and explains future work.

2 Data Stream Management Systems

An increasing usage of active sensors, which produce continuously and potential infinitely data—so-called data streams—creates a new class of application that have to process several data streams in real-time. The high demand of time and the potential infinity avoid to save the data streams into a database for processing them afterwards. Due to this fact, such tasks are normally done by hard-wired hardware or fixed programs. These approaches, however, are mostly custom-designed for each application and only offer low adaption, flexibility and scalability. As an alternative approach, data stream management systems (DSMS) are researched in the past few years. These systems and their query processing generally offer the same properties like a database management system (DBMS), e.g. a declarative query language, an integrated query processing and optimization or a semantic correct and deterministic execution of all queries. But DSMS continuously evaluate active data streams while DBMS only evaluate static data once per query. The main characteristics and functionalities and their differences to DBMS are explained in the following.

2.1 Data Streams and Time

DSMS are designed for processing of data streams. A data stream is a continuous sequence of data tuples. In most cases a data tuple equates to a sensor measurement. Each data stream has—similar to DBMS—a fixed schema, which is a list of attribute definitions where each attribute definition describes at least one entry of the data tuple. Therefore, a data tuple (also often called element) is an instance of the data stream schema and contains several values. The data is actively generated by the sensor, so that the DSMS does not know when or how much data the sensor produces. Thus, the DSMS is data-driven and processes the data, each time when a new element arrives at the system. On the contrary is a DBMS demand-driven and processes the static data if a new query is given.

Furthermore, the time plays a decisive role. Each element of a data streams has a timestamp, which normally is either the time of measurement or is set by the system when the element arrives for the first time. Therefore, the data stream is a sequence of events that is sorted by time. This aspect allows the DSMS to process only data that chronologically correlates, e.g. the same period of measurement. Further like explained in [20], the timestamp can be extended to a timeinterval (a start timestamp and an end timestamp) that indicates the validity of an element. This makes the processing of infinite data possible, because of the fact that the validity is bounded, the processing only looks at a section of the whole data streams. Those sections of a data stream is called a window. It is possible to define several kinds of windows or rather validity timeintervals. The DSMS can according to requirements, e.g., continuously look at the last 10 minutes or split the data stream into disjoint subsequences of 20 elements. The definition of windows is dependent to application and is therefore part of the dedicated query.

2.2 Queries

Like in DBMS a DSMS supports declarative queries. Currently there are a lot of languages, because there is no standard like SQL. The languages, however, are mostly adapted from SQL where it has been extended with temporal semantics to express, e.g., the mentioned windows. The following example shows a query where the sensor `thermo` with the schema `(time, temp, room)` measures the temperature and the sensor `photo` with the schema `(time, light, room)` measures the light intensity. The values of both sensors are joined if they are from the same room. The result is used to calculate the average temperature of the last two hours and the maximum light intensity of the last hour. The output only shows values that are measured in the living room.

```
SELECT AVG(temp), MAX(light)
FROM thermo [RANGE 2 HOURS], photo [RANGE 1 HOUR]
WHERE thermo.room = photo.room AND room = 'livingroom'
```

If a user or an application makes such a query, it is received by the system which commits the query to a query processing. Furthermore, there are some applications that cannot express their information needs through a declarative language, because they have to determine the order of aggregations, filterings, joins or have other special needs. Thus, there are in addition to SQL-like languages also other possibilities for functional or procedural queries.

2.3 Query Processing and Optimization

If a new query is given to the DSMS, it passes through—like in DBMS—multiple steps of a query processing. First, the query is translated into an equivalent query plan that exists of logical operators (cf. Fig. 1). Each logical operator represents a specific execution semantic. The part `room='livingroom'`, e.g., is realized as a logical selection operator (filter). This logical representation allows among others an optimization without loosing any semantics. It is, e.g., possible to switch, merge or delete several operators in the query plan. Figure 2 shows an

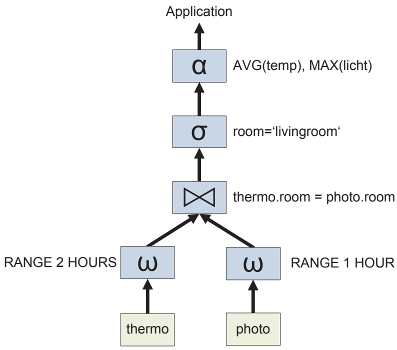

Fig. 1. Logical Query Plan

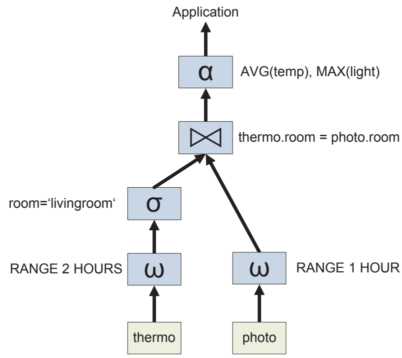

Fig. 2. Optimized Query Plan

optimized query plan for the one in Figure 1. The selection is previously executed so that only less data has to be process by the expensive join operator. The logical query plan does not contain any implementations for the real execution of the query plan. On the hand it is not necessary for the optimization and on the other hand it allows to generate several physical query plans for one logical query plan. One logical operator, e.g., may have more than one physical implementation (e.g. other algorithms) and each implementation has its pros and cons. Therefore, a cost-based optimization decides what physical query plan probable produces the fewest costs. Normally there are a lot of running queries in a DSMS, which allows a so-called *Query Sharing* where existing queries or parts of them are reused. e.g., there will be only one physical query plan although the user may sent a query a second time, because it already exists in the system. In addition to an optimization before the query is durably installed in the system, there is also a dynamic optimization during the execution. The system can detect changes of the behavior of different data streams and react. If, e.g., the order of two selection operators is not optimal, then the system has the ability to switch these selection operators at runtime.

2.4 Execution

First, the physical query plan is bounded to the sources (normally the sensors) and the sinks (the application or a graphical output). If a sensor sends a new element to the system, it runs from the source through the physical query plan to the sinks. Each operator that is passed by the element executes its specific operation onto the element. A selection operator, e.g., evaluates the predicate (in the example above `room='livingroom'`). If the element fulfills the predicate, it is forwarded to the following operators. Otherwise the element is discarded if the predicate is not fulfilled and the next element is evaluated.

Although sensors are active and therefore define the processing, it is possible to use buffers. These are special operators that buffer all element unless they are explicit invoked to continue. The invocation is managed by a scheduler that selects the buffer to invoke with the help of a scheduling strategy. There exists several scheduling strategies, like a rotational (round robin), a load-based or a priority-based buffer selection.

3 DSMS and AAL

This section explains several techniques and areas of DSMS and illustrates how they can be used in AAL and sensor data processing and what advantages compared to other concepts they have. A more detailed overview over concepts and realizations in DSMS is presented in [13] or [12].

3.1 Data Stream Processing

The most important advantage that DSMS offer to (AAL-)applications is the universal processing of data streams. The DSMS provides several concepts for an efficient handling of continuous and high frequent data. For this, the query processing plays a major role. The application has only to formulate a query and can ignore things like execution semantics or optimization. A query can be used, e.g., to filter elements out or to join two or more streams. It is also possible to evaluate certain functions or calculations of specific values. Furthermore, aggregates like average, maximum or sum can be computed. These processing mechanisms do not have to be implemented for each new application.

3.2 Temporal Semantic

The temporal order of measurements provides an extensive additional information. In the area of activity recognition, e.g., it is important, if a person switches the stove on and then uses the kitchen door or vice versa. In the first example, the person would leave and in the second example the person would enter the kitchen. Therefore, the interpretation of the activity differs. If the timestamps are completely ignored, informations are lost. According to the example before, the system can only identify that the stove is on and that the door was used, but has no idea about the order. Therefore, an application has to be calculate the activity model with two possible scenarios. This leads to unnecessary uncertainty of the context model. Thus, the usage of timestamps increases the accuracy of the context model.

The additional usage of timeintervals or rather windows in a DSMS allows it, to bring only such events together that have a temporal correlation to each other. In the previous example, the events *stove on* and *used door* can only be meaningfully correlated, if they occur within a specific time period like 15 minutes and not a whole month. Thus, there only must be defined a window for these kinds of events and the DSMS takes care of the semantics, so that only events are joined that are in the same time window.

3.3 Declarative Queries

First of all, the advantage of a declarative query is in general to describe *what* the answer should contain and it is not necessary to describe *how* it is computed. A SQL-like query language in a DSMS makes it possible, e.g., to compute the average of the last hour, but one has not to declare how this shall be computed. Thus, the user normally don't need any deep knowledge of data stream processing. This minimizes for the one hand the orientation and training and on the other hand the time that is needed for the implementation. The developer has only to design the query and don't need to think about complex algorithms for data streams, which additionally have to be deterministic, semantically correct and efficient for potentially unbounded data. The DSMS makes sure, that the declarative query is executed in that deterministic and semantically correct way. This significant property is often unattended by some applications, because mostly it is not their actual focus. But, such applications rely on such a processing, so that they have to implement it. This may be another source of errors, that can be avoided by a DSMS. Only the formulation of a correct query is crucial. A DSMS allows the user to rephrase the query and change the queries, if the previous query does not produce the desired results. Thus, no extensive code modification is needed.

3.4 Query Optimization

A DSMS optimizes the processing of data streams on several areas. The static optimization reorganizes the query plan before the execution, so that the used query plan is as efficiently as possible. Furthermore, a dynamic optimization can be used during the execution. If, e.g., two selection operator (filters) are executed in succession, it is possible to switch both operators, if only the runtime reveals that the second selection operator filters more elements than the first operator. Therefore, it is not necessary to adapt the application from time to time by hand, which is very helpful if this has to be done at regular intervals (e.g. seasonal).

Most applications that are implemented by hand are often (statically) optimized for a specific use case in advance. Therefore, they usually don't use a dynamic optimization. Thus, they either assume that data streams don't change over time or the processing is afterwards adapted by hand. However, this long-winded variant avoids a temporary and prompt dynamic optimization. With the use of a DSMS, the application gets a preprocessing of data streams that is as optimal as possible and the developer does not need to declare or even implement the optimization.

3.5 Shared Queries

Besides the static and dynamic query optimization, the DSMS can decrease the system load and the memory usage by a shared executing of whole queries or parts of a query. If a user would like to compute the average temperature and light in the living room and another user would like to have the concrete temperature and light values from the living room, both queries are equivalent except for the computation of the average. Thus, the DSMS does not create a second query plan, but reuses the existing running query plan. This approach allows the reduction of system load and memory usage, which makes it possible to process more data and therefore to increase the exactness. Furthermore, the preprocessing of several sensors or rather applications can be consolidated into one system to get a less overall load.

3.6 Realtime Processing

Each computation in a DSMS is done in realtime. That means, that in contrast to a DBMS the goal of DSMS is to process as quick as possible. Therefore, queries are not saved before they are long-winded computed, but are directly processed by the main memory. There are in addition specific algorithms, so that the results can be computed in a faster way. This makes it for concrete applications possible to react as soon as possible. However, this kind of processing still allows to save the data into a database. A DSMS provides the possibility to save, e.g., only essential or already aggregated data to reduce the load on the database.

4 Extensions

Possible fields of application have led to new extensions and adaptations to cover other application problems and contexts as well. Extensions that are also interesting for concepts in AAL are shortly described in this section.

4.1 Temporal Pattern

A DSMS has the ability to detect simple events as well as simple patterns. However, it is not possible to detect complex patterns that consider temporal characteristics. Thus, the complex event processing (CEP) deals with the recognition of such patterns. e.g., an application can detect a temporal pattern to decide if a person sits or lies on a bed. A possible pattern may be to detect if the weight increases for a few seconds before it rapidly sinks over 10 %. There are also questions like if there are other events between the proper pattern are allowed or not. SASE+ [14] e.g. allows to define and analyze temporal patterns.

4.2 Data Stream Mining

The classical data mining that comes from the database context can be divided into three disciplines. Due to the fact that data streams may be unbounded and there is only a fix-sized main memory available, not all classical data mining algorithms are directly applicable. Therefore, there are incremental approaches that can be used for data mining on data streams. In the context of data streams there are also two other techniques besides the three classical disciplines. On the one hand the time series analysis can be used to detect trends on the streams.

On the other hand it is possible to detect concept drifts. Concept drifts are unpredictable changes of a data streams. These concept drifts can be used to adapt other (classical learned) models, if the data stream values changes over time (e.g. seasonal). Gaber et al. [11] give an overview to several techniques and algorithms of this area. Data Mining is an important technique in AAL, because it is often the basis of the real application. Thus, the classification can be used to distinguish between normal or abnormal behavior. Or the clustering may be used to generate objects from scatter-plots that are given by laserscanners. Therefore, data stream mining brings the two required techniques, data mining and unbounded sensor data processing, together.

4.3 RDF Data Streams

A lot of systems in AAL use RDF or ontologies to manage the context knowledge. Normally, a RDF database (like the Jena framework) is used for processing the RDF data. If the RDF data is available as a data stream and it is just saved into a database, there are the same problems that exists with classical data streams and databases. Thus, there are approaches for a data stream based RDF processing, where also an extended variant of SPARQL (e.g. StreamingSPARQL [5] is provided.

4.4 Spatial Data Streams

Data streams with geographical information are called spatial data streams. For this, DSMS are often extended with techniques from a geographical information system. Thus, the DSMS has the ability to compute, e.g., the intersection of two polygons or something like that. Due to the fact that the temporal behavior of the DSMS plays also a role, the streams are often called spatio-temporal data streams (cf. e.g. [22]). The processing of spatial data streams may be used in AAL to compute the motion or location-based data inside of a home. Afterwards this data can be used for a motion based analysis. There are also some approaches for object-tracking, like it is done by [4] in the context of driver assistance systems to realize an adaptive cruise control.

5 DSMS in AAL-Architectures

This section shows how DSMS can be embedded into the environment of AAL applications. We propose three possible scenarios and discuss relating to possible fields of application their pros and cons.

5.1 DSMS per Application

The simplest variant for using a DSMS in AAL is the integration into a single application. This is, e.g., shown in Figure 3 for two applications. This variant is particularly suitable for new applications by building directly on a DSMS and the

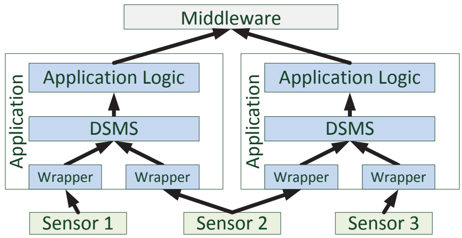

Fig. 3. DSMS per Application

middleware has not to be adapted. However, this variant has the disadvantage that multiple instances of a DSMS are used, thus many optimizations like query sharing are no longer possible.

5.2 Central DSMS with Data Bus

Another possibility for integrating a DSMS into a AAL application environment is shown in Figure 4. Here, the DSMS is provided as a service within a

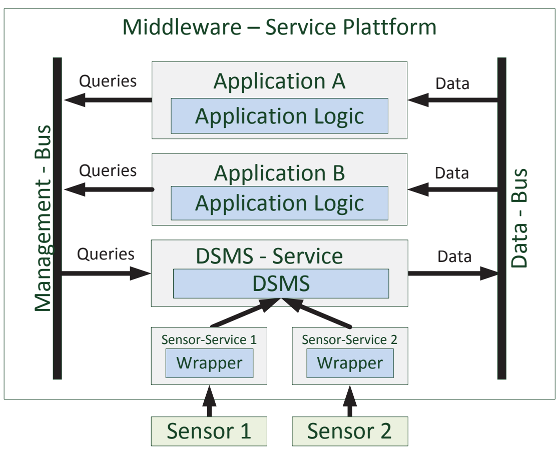

Fig. 4. DSMS Bound to a Bus

component-based architecture. The advantage here is that existing architectures can be easily extended by a DSMS. In this variant applications can—depending on the architecture—either bind the DSMS as a service and use it directly or the application can put its queries as a message on a management bus. The DSMS can then evaluate the message and push the resulting data stream to the data bus, so that it can be gripped there by the application. The disadvantage of this variant is that either there is a direct dependency to the DSMS service or a possibility must exist in order to communicate with the DSMS (e.g., via a management bus).

5.3 Central DSMS with Direct Binding

The DSMS can be used as part of a centralized middleware (such as the universAAL platform [16]). Figure 5 shows a possible architecture of this. In this

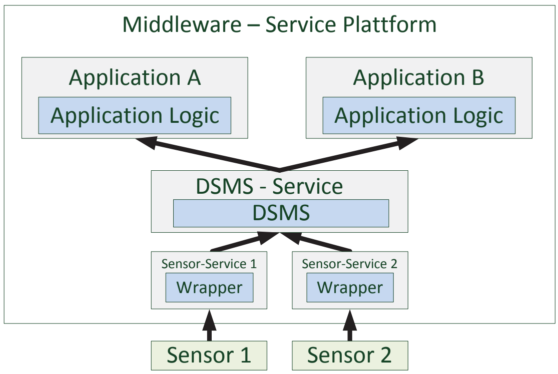

Fig. 5. DSMS as a Central Component

scenario, all sensors and thus the data streams are directly connected to the DSMS. This ensures the preprocessing of the data streams and that only relevant information is forwarded to the (previous) middleware. Since this version makes the complete processing by the DSMS, all optimization possibilities are exploited. Thus, e.g. the same processing steps are not redundant and only run once in the DSMS. By connecting to the middleware an abstraction can be ensured by the middleware only communicates with the DSMS. Thus, e.g., the middleware requests queries or binds the sensors to the DSMS. The main difference to most available middleware architectures in the AAL field is that the raw sensor data are not longer put on a service bus. Busemann et al. [7] showed that in this context an essential improvement of latency and throughput, if the processing of highly frequent data is not done over a service-oriented architecture (SOA), but is done directly by a DSMS. They also show in this context a hybrid approach where SOA and DSMS are combined. In this scenario a central database can be still used by saving only the relevant resulting data streams of the DSMS. Also, an RDF database can be used to provide and compute the context model centrally in the middleware. RDF data streams can also be preprocessed by an RDF extension for DSMS (see section 4.3) before the data is stored in the RDF database. The disadvantage of the variant with a central DSMS and direct binding is the increased cost of integration into a middleware, so that this may not be appropriate for existing middlewares.

6 Example: Odysseus in AAL

To show an initial feasibility of the use of DSMS in AAL environment, a prototype was developed, which shows a vertical cut through all necessary layers of a typical application for AAL. In order to keep the sample application understandable, it is relatively simple. As an example, a bed with weight sensors at each of the four bedposts was used. Furthermore, there is a light sensor on the roof. Goal of the application is to identify if a person is sleeping, sitting or standing by using the time of the day (brightness) and the weights of the bed. And if the person, e.g., standing up at night, then the lights should be turned on, so the person can safely leave the room.

As the DSMS within the application Odysseus [18] was used. Odysseus is a Java-based DSMS, which can be fully integrated as a component-based application in an OSGi environment. By implementing the various mechanisms and strategies as separate components, Odysseus is also a framework. This may be, e.g., if necessary extended with further data processing mechanisms or models. The data can be transferred via various wrappers to Odysseus, which processes the data afterwards. After the processing in the DSMS, the results are provided to an application. For this purpose, usually a socket connection is used to send the data to the application. Due to the extensibility of Odysseus, it is also possible to implement own endpoints, which process the resulting data.

The sample application is built in three layers (see Figure 6). The lowest layer contains the five sensors, which transfer their data as a stream to the a wrapper that translate the data into a common format. In this step all four

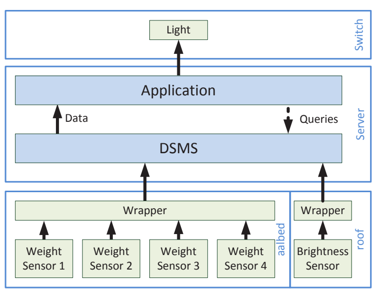

Fig. 6. Architecture of the Example Application

weight sensors are combined into one data stream, so that. with light sensor there are two data streams connected to Odysseus. Afterwards, the processing from Odysseus depends on the queries that have been provided by the application from the uppermost layer of the server.

In the following, the procedure of the implementation is described to give an impression of how the application can use the DSMS. The sensors could be integrated without problems, because they provide their data via the wrapper in a specific format, which can be understood by Odysseus. The sensors are distributed over a network on different nodes (*aalbed* and *roof*). Therefore, the sensors must be known to Odysseus as data streams before Odysseus can connect to them. For this, the application requests the following query:

```
CREATE STREAM weight
(time TIMESTAMP, id INT, weight DOUBLE) AT aalbed:4321;
```

This query indicates that a data stream with the name `weight` shall be created. This data stream sends relational tuples that have a fixed schema. This is a timestamp of the measurement (`time`), an `id` for each of the four weight sensors and `weight` as the actual weight measurement. Furthermore, the query declares that Odysseus can connect via port `4321` to the host `aalbed` with the sensor in order to receive the data. Afterwards, the following query is made for the brightness sensor:

```
CREATE STREAM light
(time TIMESTAMP, lumen INT) AT roof:3333;
```

Odysseus automatically connects to both sources and receives their data. However, since no further queries for evaluation of the data streams have been made so far, all incoming data is discarded by Odysseus. Accordingly, the application must first submit a query. This includes already some of the application logic:
R1: A person is sleeping when the average weight is 15 kg
R2: If 80% of the weight is on the front sensors (id is 1 or 2), the person sits
R3: If the person stands up and it is dark, then turn on the light

The previous mentioned requirements can now be implemented via a query. We assume here that always sequences of a weight value for each sensor arrives at the system. In this ways we can e.g. define a window of four tuples, so that the average can be continuously measured. To implement *R1*, the following query can be used to supply only values, if the average is under 15 kg to express that the person is not sleeping.

```
SELECT time FROM weight [RANGE 4 TUPLE]
WHERE AVG(weight) < 15;
```

If the person does not lie, he can still sit up in bed. To exclude this case, the requirement *R2* must be negated. Here, the query

```
SELECT SUM(weight) FROM weight [RANGE 4 TUPLE]
WHERE id=1 OR id=2;
```

returns the sum of the two front sensors. This would be greater than 80% of the total weight, if the person would sit. Since this case is to be excluded, the ratio has to be less than 80%. Accordingly, the above query has to be embedded as a nested query:

```
SELECT SUM(weight) FROM weight [RANGE 4 TUPLE]
WHERE SUM(weight) * 0.8 >
(SELECT SUM(weight) FROM weight [RANGE 4 TUPLE]
 WHERE id=1 OR id=2);
```

We can now combine this query with the first query to obtain a resulting data stream that contains only a data element, if both requirements are not given, which means that the person is standing:

```
SELECT SUM(weight) FROM weight [RANGE 4 TUPLE]
WHERE AVG(weight) < 15  AND SUM(weight) * 0.8 >
(SELECT SUM(weight) FROM weight [RANGE 4 TUPLE]
 WHERE id=1 OR id=2);
```

For a better overview of the resulting data stream, it can be made accessible via its own name, which is similar to the view concept in databases. For this, the query can be wrapped as follows:

```
CREATE VIEW standing(SELECT SUM(weight) ...);
```

This data stream can now be joined with the data stream of the brightness sensor to add the current brightness. In addition, however, only values shall be delivered when the brightness of the last second is above 100, because then it is dark. This gives the following query:

```
SELECT * FROM standing, light [RANGE 1 SECOND]
WHERE lumen < 100;
```

The data stream that is generated by this query always delivers an element, if the person stands and it is dark. The application can use this, e.g., to let the light on as the data stream contains elements. Alternatively, it is possible to adapt the query, e.g., so that it only delivers a state (sleeping, sitting, standing) each five seconds.

7 Related Work

In addition to the framework Odysseus [18] that was used, there are other DSMS such as STREAM [2], Borealis [1], TelegraphCQ [9] or PIPES [20]. These DSMS have different approaches for data models, semantic processing or implement different optimization strategies. Odysseus was used because in contrast it can combine multiple data models, semantics or strategies. e.g., Odysseus also has in addition to a relational a RDF based processing [5], which makes the system interesting for the context of AAL. However, window semantics and operator processing that are considered here, are mainly based on [20].

In the health care PIPESmed [19] shows how PIPES can be used as a DSMS in medicine. Here, however, only a simple data stream with medical context was simulated. Furthermore, Brettlecker [6] shows a demonstration of how the heart's activity can be processed through a DSMS. It uses, however, a different model, e.g. with specific and not general operators like selection and projection. In addition, it does not use any query language to describe the processing.

For the heterogeneous integration of different sensors several universal platforms such as SCAMPI [8] as well as specialized for AAL were designed. AAL focused systems like the GAL middleware platform [10], OASIS [3], PERSONA

[23], or ALTO [25] have, e.g. with a service-oriented or an agent-based architecture, various approaches to integrate a variety of sensors and applications. Currently, with universAAL [16] there is another platform that tries to summarize the advantages of several previous platforms. The focus of the systems, however, lies mostly on the integration of heterogeneous sensors and applications. But, the concepts presented here put the focus on the sensor data processing. Therefore, the use of a DSMS is not a new middleware approach, but rather shows how a middleware can be extended by a DSMS to allow a more flexible and optimized processing of potentially infinite sensor data. In the context of middlewares CEP is often used as an alternative term for data stream management and its concepts.

8 Conclusion and Feature Work

This paper presents an overview how data stream management systems (DSMS) can be used in Ambient Assisted Living (AAL) and what advantages they offer over existing systems. The use of an universal and flexible solution for handling continuous sensor data streams not only provides an abstraction layer and not only reduces the development costs, but also provide some other additional benefits. These are, e.g., defined semantics and a deterministic processing, which is also optimized by the system. Enhancements such as RDF and SPARQL, or data stream mining are provided by the DSMS as universal mechanisms, which are in the context of AAL often implemented "by hand". We have shown an example how an application can be implemented with DSMS Odysseus.

The goal is the use of Odysseus in a real environment as a central system for sensor data processing. For this, Odysseus is currently being tested in the IDEAAL apartment [21], the living lab at OFFIS - Institute for Information Technology. For this, various sensor connections are currently being developed to be able to consolidate the partially heterogeneous sensor protocols and applications over Odysseus. Furthermore, we explore how learning algorithms and models can be integrated in a DSMS to be universally usable to also allow a optimized, reusable and query-driven processing after the preprocessing, because at this phase or layer AAL systems mostly use some kind of learning methods.

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TinySEP - A Tiny Platform for Ambient Assisted Living

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Abstract. Many AAL software platforms developed in the last years are not widely accepted outside of their projects, because of their high complexity. Moreover, many successful software frameworks are based on the thin architecture approach: they implement only basic functionality, being more flexible in practical use cases. In this work we present the **Tiny S**mart **E**nvironment **P**latform. **TinySEP** is a compact platform, which makes use of two approved concepts of the software engineering. It combines the benefits of complex modular platforms and proprietary monolithic solutions.

Keywords: TinySEP, Tiny, Smart, Environment, Platform, AAL, framework, driver model, device, signal-slot model.

1 Introduction

Health insurance companies, their customers and individual care-givers create numerous use cases for Ambient Assisted Living (AAL) systems. Moreover, the AAL systems are not limited to medical services. They can provide more comfort in everyday life (e. g. automatic light control), higher security (e. g. burglar or fire alarm) or automatic energy saving. The focus for health insurance companies is a manifold use in the medical area. For example, fall detection *and* supervision of daily medication *and* integration of tele-care services shall be supported at the same time. Furthermore, the AAL system has to adapt itself automatically to the given boundary conditions like already installed hardware of the actual housing situation. If other services are demanded in future or the boundary conditions change (e. g. structural measures), the system has also to readjust itself. From the developers point of view it shall be easy to integrate new hardware and new services at any time. Finally, AAL systems have to be reliable and cheap enough to be interesting for a wide customer segment.

A typical AAL system consists of several sensor/actor nodes (called AAL hardware in the following), a central computational unit and a central AAL software platform. The required AAL hardware is today available in form of wired solutions like KNX[1] or wireless solutions like Wireless Sensor Networks (WSN,

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

e. g. AmICA [8]). Many standards for wireless communication, like WLAN or ZigBee[2], are also available today. Netbooks or set-top boxes are common used as computational units.

As for 2011 there exists no standard for an AAL software platform. That is one of the reasons, why AAL systems are not wide spread despite of years of intense research work. Although a lot of different, modular AAL platforms were designed in research projects, for concrete, practical projects proprietary, monolithic systems are often developed. A lot of platforms are universal and flexible, but require significant time to understand and install the overall system. Moreover a platform typically requires to be adapted to realize special functions. Thereto, the complex entire structure has to be understood.

In many cases most of the complex functionality of a "heavy" universal framework remains unused in practice. The most famous example is the ISO/OSI layered model: the TCP/IP stack, which is used in reality, does not implement a lot of the proposed layers. In the area of Wireless Sensor Networks, TinyOS [7] as a flexible, thin and resource-saving operating system has established.

In this paper we present the **Tiny Smart Environment Platform "TinySEP"**. TinySEP bridges the gap between the two approaches used so far and combines the advantages of both. It makes use of two very successful and frequently used concepts of software engineering: the driver concept and the signal-slot model. TinySEP is designed for developers of AAL solutions and can be seen as the lowest common denominator. While giving the developers of AAL hardware, intermediate services and AAL services maximum freedom, TinySEP connects the single elements to one AAL system.

The paper is structured as follows: Next section shows the requirement of a modern AAL software platform. State of the art is presented in section 3. Base models of TinySEP and their design are depicted in section 4. Section 5 shows how the layered model is used in TinySEP. The practical use of TinySEP is explained in section 6. Section 7 gives a closer look at the openAAL and universAAL project. The last section summarizes the paper and gives an outlook how TinySEP can be used in future.

2 Requirement of a AAL Platform

The following **functional requirements** are essential for developing an AAL platform:

- Hardware abstraction
- Open system interfaces
- Changes of hardware and software at runtime
- Sensor fusion and context management
- Mechanisms for self-configuration and -adaption

[2] `http://www.zigbee.org/`

These are the **non-functional requirements**:

- High re-usability of single components
- Internal system communication and ontologies
- High usability for the developer
- Low resource consumption
- Easy changeability and portability

Table 1. Comparison of fulfilling the requirements of TinySEP, monolithic systems and modular AAL platforms; [1]only high for internal developers, who know the system structure

	TinySEP	Monolithic systems	Platform-based systems
Hardware abstraction	+	−	+
Open system interfaces	+	−	+
Changes of hardware and software at runtime	+	−	+
Sensor fusion and context management	+	**o**	+
Mechanisms for self-configuration and -adaption	+	−	+
High re-usability of single components	+	−	+
Internal system communication and ontologies	+	−	+
High usability for the developer	+	+/−[1]	−
Low resource consumption	+	+	**o**
Easy changeability and portability	+	**o**	−

3 State of the Art

Home emergency call and classic home automation systems can only be partly seen as AAL systems. Beside them, existing AAL software can be divided in two classes: proprietary, monolithic systems and modular AAL platforms. Both classes are described in the next two subsections. They are evaluated based on the criteria given in section 2. A summary is presented in Tab. 1.

3.1 Monolithic Systems

Proprietary, monolithic systems are developed bottom-up for concrete projects and problem statements. The functional requirements as well as the boundary conditions are well-defined from the beginning. As a result, these AAL platforms are optimally adapted to the problem statement. Developers can use their well-known paradigms resulting in a faster development cycle. The resource consumption is minimized by implementing only the required functionality. Thus, the underlying hardware can be very compact and energy-efficient.

The biggest disadvantage of monolithic systems is their low re-usability. Own concepts for hardware abstraction has to be developed, sensor-fusion is highly dependent on the algorithms and a context-management as well as ontologies are often not existing. Open system interfaces are very rare. Changes to the software require restarting, manual interference or even recompilation. Another downside is, that mechanisms for self-configuration and -adaption are often missing. As a result, those systems have to be manually reconfigured for every flat configuration and every time new services are introduced. The advantages in the development phase are often neutralized, because simulators and methods of early debugging (Virtual Platform concepts) are not available. In many cases, external developers cannot integrate own services, because those monolithic systems are often closed-source. Consequently, more and more monolithic platforms are developed each year, each requiring time and money.

To sum up, monolithic systems fit well for projects with a well-defined functionality, clear boundary requirement and low probability of late changes and extensions. If new functionality is needed or the system has to be used in different, but similar environments (other flat, other hardware etc.), more time is needed and higher costs rise up.

Examples for monolithic AAL systems are the EU project EMERGE[3] [5], the Assisted Living project PAUL[4] [3], which realizes a inactivity recognition based on motion sensors and the demo flat of the "Verband Sächsischer Wohnungsgenossenschaften e. V." in Burgstädt/Germany[5].

3.2 Platform-Based Systems

Modular AAL platforms are developed top-down. Most important are universal applicability, high flexibility and re-usability. Mechanisms for hardware abstraction and open system interfaces are integrated to connect with future AAL hardware and AAL services from third-party supplier. A running system can be changed without a re-start. Normally, AAL hardware as well as AAL services can be removed and added while the systems is running. Sensor fusion is used to generate general context information, which can be used by different AAL services. One example is the "Context Manager" of SOPRANO [6]. Together with other components, like the "UI Engine", the Follow-Me-User-Interface or the localization service of SerCHo [1], mechanisms for self-configuration and -adaption are realized. Encapsulation of functions leads to a higher re-usability.

Many AAL platforms require knowledge of specific programming languages and tools. For example, to work with SerCHo [1] one has to learn the Business

[3] http://www.emerge-project.eu/

[4] http://assistedliving.de/

[5] http://www.wbg-burgstaedt.de/news_details.php?Pos=23

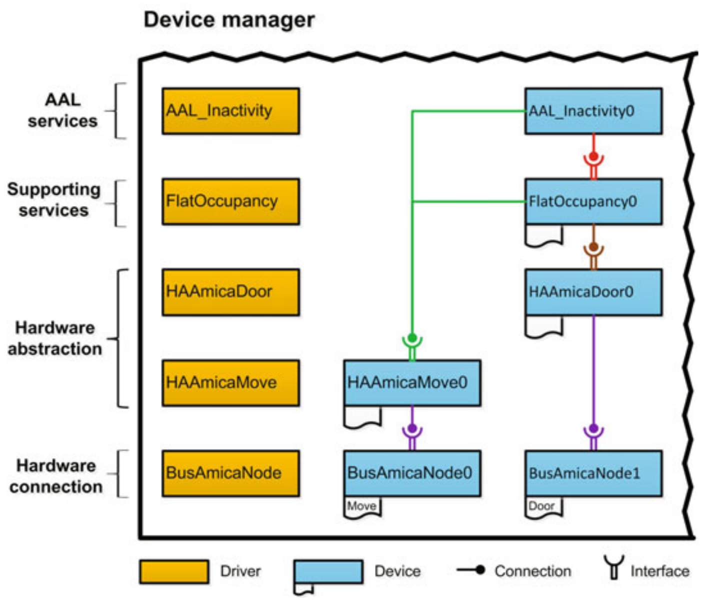

Fig. 1. TinySEP sample configuration

Process Modelling Notation (BPMN). AAL solutions, which are already developed in other programming languages, have to be re-implemented and tested again. Changes and extensions of the platform itself are possible, but need a deep knowledge of the complex software. Beside that, there are practical barriers like urgent memberships. Examples are OSAmI[6] [2] or the Connected Living e. V.[7] with costs. Most of real installations require relatively simple hardware and have no need for most complex functionality provided by the frameworks. One example is the german BMBF project "TSA - Technisch-soziales Assistenzsystem" (TSA - technical-social assistance system)[8]. SerCHo is not able to exploit its UI Engine, if only *one* TV output is present. Modular AAL platforms offer often a *too big* functional, confusing range. That is the reason, why often monolithic systems are developed again, because this is seen as the "faster and easier" way.

Other examples of modular AAL platforms are AMIGO, GENESYS, OASIS, MPOWER and PERSONA, which advantages shall be melted in the universAAL project[9] [4].

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[6] http://www.osami-commons.org/

[7] http://www.connected-living.org/

[8] http://www.spellerberg-stadtsoziologie.de/forschung.php?id=15

[9] http://www.universaal.org/

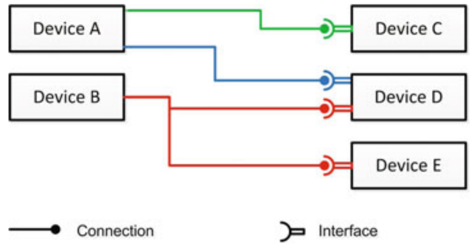

Fig. 2. TinySEP Interfaces

4 TinySEP

Ambient Assisted Living (AAL) systems are typically event-driven: for example, when someone enters a room, the movement detector registers it and the light is switched on. In parallel, the information is forwarded to the inactivity recognition system. Thus, TinySEP is also event-driven.

TinySEP was developed after the analysis of 12 typical services in the areas of healthcare monitoring, comfort, security and energy saving. Each AAL platform has to consist of at least four layers:

– Hardware connection
– Hardware abstraction
– Intermediate services
– AAL services

Each layer is reflected in TinySEP. The main focus during TinySEP development was to keep the complexity as low as possible while fulfilling all requirements for a AAL system described in section 2. For implementing the platform, we have adapted two concepts from software engineering world: the driver concept and the signal-slot model. With the help of these two models, all layers can be represented. Fig. 1 shows a exemplary system status.

4.1 Drivers and Devices

The **driver model** follows the 4-layer model and is used in most modern operating systems. An operating system is able to access the hardware with the help of drivers. Further, a driver creates so called **device** objects, accessible by other drivers and devices. For example, a USB controller driver creates a new USB device, if a mouse is plugged into a the computer. This device provides raw data from the USB mouse. A USB mouse driver creates a second device that converts raw data into a common format (e. g. cursor moving instructions).

TinySEP utilizes a similar driver model. Each of the four layers listed in the previous section can be represented in TinySEP. Devices are objects that encapsulate certain functionality. For example, Devices can be used for hardware abstraction or for AAL intermediate services. Additionally, each Device object

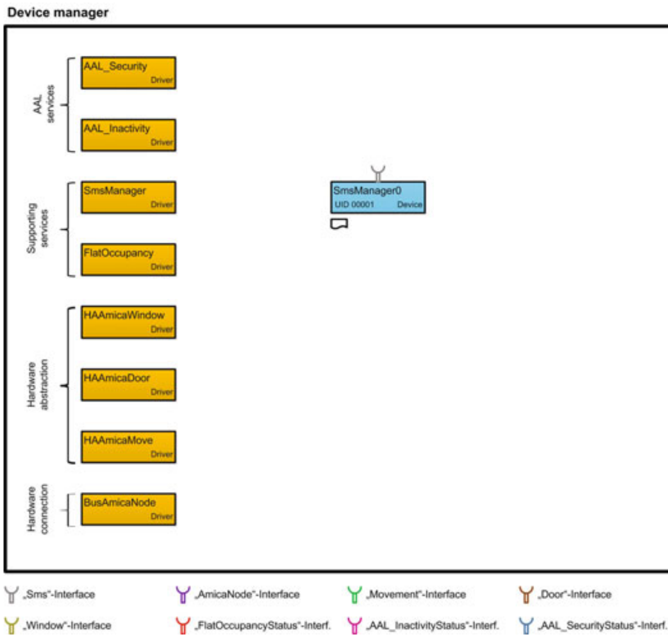

Fig. 3. TinySEP example scenario, part 1: after first startup

stores internal configuration information, which can be accessed from outside. If e. g. a door sensor is abstracted, the corresponding Device provides the information about the location of the door in the flat or if it is an inner or outer door. Other Devices need this information to decide, if they want to connect to the Device or not. Section 5.1 to 5.4 give practical examples.

4.2 Interfaces

In a event-driven system, objects can be connected with the help of the signal-slot model[10]. Signals are "messages", which are sent to slots. A signal can be sent to several slots. A slot can receive several different messages.

The signal-slot model is used in TinySEP to interconnect Devices. To enable this, the signal-slot model was extended in two ways. First, several signal-slot pairs are bundled to so called **Interfaces**. Second, always a bidirectional connection is established. Thus, Device A is able to send different signals to Device B. Device B is also able to send data back to Device A. An overview is shown in Fig. 2.

[10] First use in the QT library, see `http://qt.nokia.com/`

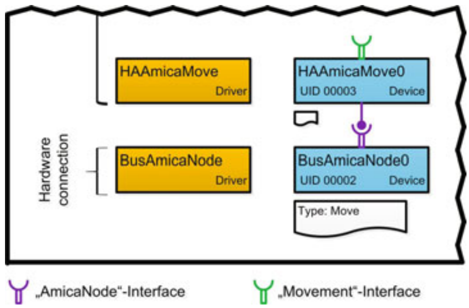

Fig. 4. TinySEP example scenario, part 2: after installation of the first AmICA WSN movement node

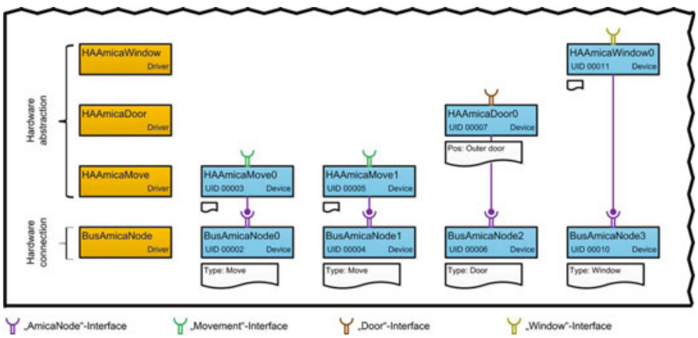

Fig. 5. TinySEP example scenario, part 3: after installing of all AmICA WSN nodes

4.3 Device Manager

All Drivers, Devices and available Interfaces are administrated by the **Device manager**. New Drivers register them-self at the Device manager and tell him, about which new interface types they want to be informed. Devices also register at the Device manager and tell him, which interfaces they provide and with which interface types they want to connect. The Device manager implements only minimal functionality, while the intelligence of the system is realised with the help of Drivers, Devices and their Connection with each other. In Fig. 1 the components of TinySEP are shown exemplary.

5 Layered Model of TinySEP

We demonstrate the role of TinySEP on two typical AAL service examples. An **Inactivity recognition** sends a SMS message to a mobile phone of a predefined person as soon as there was for a longer time no activity (movement, opening of

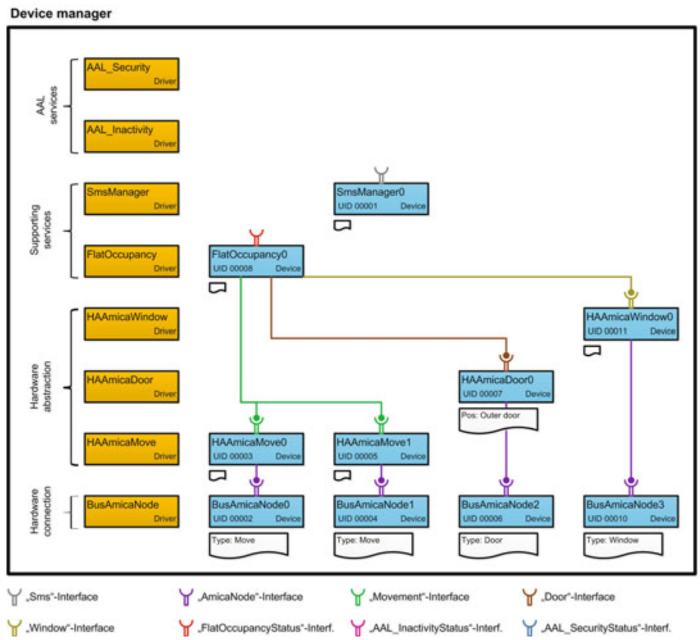

Fig. 6. TinySEP example scenario, part 4: after creation of the "FlatOccupancy0" Device

doors/windows, etc.), although a person is at home. A **Security surveillance** sends a SMS message as soon as the last inhabitant left the flat, but one or more windows are still open. Both services have to know, if anyone is in the flat and both have to be able to send SMS messages. This reusable functionality is outsourced in the two intermediate services "FlatOccupancy" and "SmsManager". All of the four layers – hardware connection, hardware abstraction, intermediate services and AAL services – are implemented with the help of the driver and extended signal-slot model.

For a better clearness, the functionality of the platform is illustrated for a flat with four AmICA WSN nodes: two for movement, one for the flat door status (open/closed) and one for a window status (open/closed).

5.1 Hardware Connection

All available drivers are loaded, when TinySEP is started. Fig. 3 show the internal status of TinySEP after startup, when no AAL hardware was installed. In this example, the following drivers are loaded by default:

- BusAmicaNode (**hardware connection**)
- HAAmicaMove, HAAmicaDoor, HAAmicaWindow (**hardware abstraction**)
- FlatOccupancy, SmsManager (**AAL intermediate services**)
- AAL_Inactivity, AAL_Security (**AAL services**)

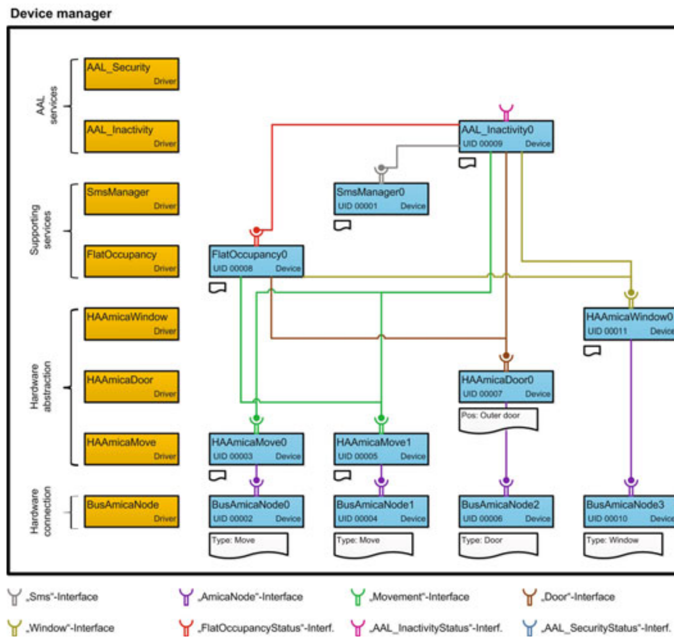

Fig. 7. TinySEP example scenario, part 5: after creation of the "AAL_Inactivity0" Device

Only the Driver "SmsManager" immediately creates a Device, because the Device is independent from other Devices. When the first AmICA WSN movement node is installed, it starts sending packets. As soon as the Driver "BusAmicaNode" receive the first packet of this new node, it creates a new Device of the type "BusAmicaNode" with the Interface "AmicaNode" and the information "Type: Move" (see also Fig. 3). With the help of this Device, other Devices can now access the node to receive raw data or to send configuration data to the sensor node.

5.2 Hardware Abstraction

Drivers of the hardware abstraction layer are responsible for converting the raw data into usable data and vice versa. The new device "BusAmicaNode0" registers itself with its Interface at the Device manager. The three Drivers "HAAmicaMove", "HAAmicaDoor" and "HAAmicaWindow" are informed about the new Device, because they might be interested in connecting to its Interface. All three Drivers read out the information "Type: Move". Driver "HAAmicaMove" creates a new Device called "HAAmicaMove0". This Device analyses the raw data and abstract it for other Devices, which can connect to the Device via the Interface "Movement". The two other drivers do not create Devices, because the can only

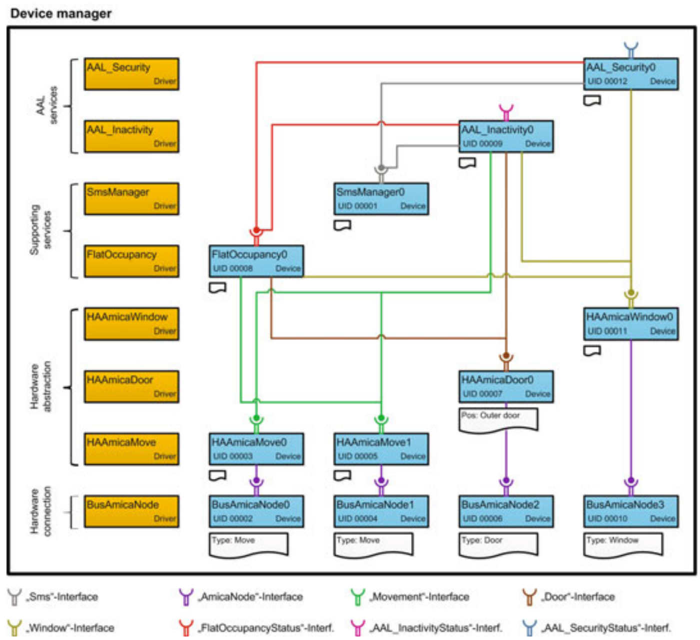

Fig. 8. TinySEP example scenario, part 6: after creation of the "AAL_Security0" Device

convert raw data from other AmICA WSN node types. The actual system status is shown in Fig. 4.

When the second AmICA WSN movement node is connected, two more Devices ("BusAmicaNode1" and "HAAmicaMove1") are created. The AmICA WSN door and window nodes are similar. Additionally, in the case of the door sensor, the user is asked, if it is a inner or outer door. In the end, two more Interface types, "Door" and "Window", are available. The actual system status is depicted in Fig. 5.

5.3 Intermediate Services

Intermediate services can also be implemented in the TinySEP driver model. There are two intermediate services in the example. "FlatOccupancy" recognizes, if at least on person is in the flat. "SmsManager" is able to send SMS messages for for other Devices. As described in section 5.1, the "SmsManager" Driver has already created a Device. Other Devices can connect to this Device via the Interface "SMS".

The "FlatOccupancy" Driver waits till the Device manager has informed it about at least one Interface of the type "Movement" and one of the type "Door" with the information "Pos. = Outer door". As soon as this is the case, the Device "FlatOccupancy0" is crated. It connects with the necessary Interfaces. In turn, it

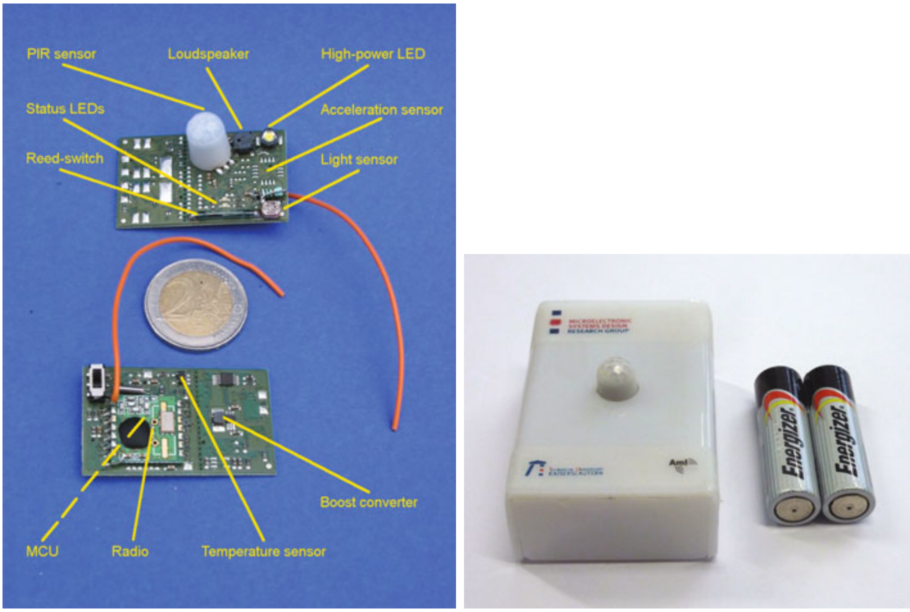

Fig. 9. AmICA WSN sensor node; without (left) and with (right) housing

provides "FlatOccupancyStatus" Interface for other devices. The actual system status of TinySEP is shown in Fig. 6.

5.4 AAL Services

Similar to the intermediate services, AAL services can also be implemented using TinySEP driver model. In this example, an Inactivity recognition and a Security surveillance service were chosen. They are represented by the "AAL_Inactivity" and "AAL_Security" Drivers. Driver "AAL_Inactivity" creates a Device, which connects to the Interfaces "FlatOccupancyStatus", "Movement", "Door" and "Windows". The actual status is shown in Fig. 7.

The "AAL_Security" Driver creates a Device, which connects to the "FlatOccupancyStatus" and "Window" Interfaces. The final system status of TinySEP is depicted in Fig. 8.

6 Real-World Setup with TinySEP

To evaluate TinySEP in real-world, two actual inhabited flats were equipped with AAL hardware. The two floor plans are depicted in Fig. 10. The flexible, easy-to-program and compact AmICA WSN platform was used [8]. In comparison to other WSN platforms, the AmICA sensor nodes support various on-board sensors like different kind of movement detectors, light sensors, reed-switches or

Fig. 10. Inhabited AAL test flats; flat A (left) and flat B (right)

temperature sensors. Further, they save more energy than sensor nodes of other WSN platforms [9]. Especially that is important for AAL, because each battery change leads to maintainance costs.

Flat A is inhabited by a 87 year old, solitarily person. It is equipped with nine movement detectors and two door contacts. Over one million real data points were collected till now. Flat B is is inhabited by a 27 year old single person and equipped with 12 movement detectors. For a concrete evaluation, 12 representative services of the areas health-care monitoring, comfort, security and energy-saving were chosen. Fig. 11 depicts the data collected during one day and the state of the "FlatOccupancy" flag. The bottom row "Calculated Flat Occupancy" shows in blue the periods, where the person was at home. Orange shows the periods, the person was not at home. The algorithms of the Driver were developed and optimized based on the real data. At the moment, further AAL service are developed and evaluated with the help of the collected data. One example is a Driver for detecting burglars based on the installed hardware.

7 openAAL and universAAL

openAAL is a joint open source initiative by FZI Research Center for Information Technologies, Friedrich-Schiller-University of Jena and CAS Software AG. Amongst other it is based on the SOPRANO project. openAAL uses the service-oriented OSGi framework and a own-defined ontology. On top, there are the core component. The Context Manager collects all sensor information and user input, combines them and offers them to the other core components. The Procedural Manager manages from a concrete installtion independet workflows, which were created with BPEL[11] processes. The Composer knows all availabe services in

[11] http://de.wikipedia.org/wiki/BPEL

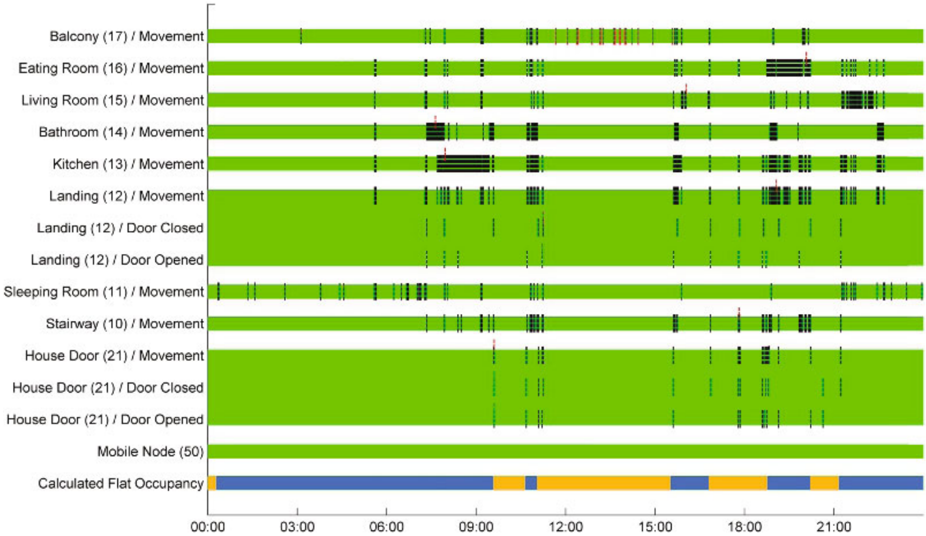

Fig. 11. Graphical representation of collected data in flat A of one day; green: function status of the WSN nodes; blue/orange: calculated periods, where a person was at home/was not at home

a concrete installation. He combines them adaptively in order to achieve the (abstract) service goals defined by the Procedural Manager.

TinySEP is not using an explicit ontology. Communication between Devices take part with pre-definfied interfaces. The centralized functions of the Context Manager, the Procedural Manager and the Composer are resolved in the single Devices. For example, in TinySEP is no central sensor fusion. Single Devices of the supporting service layer realize this function.

The EU project universAAL started in February 2010. It consolidates the most important AAL projects for the first time. The main results of the projects persona, MPOWER, SOPRANO, AMIGO, OASIS, GENESYS, VAALID and AALIANCE shall be melted. A kind of "AAL App Store" named uStore will be created. Also a so-called "universAAL developer depot" is planned. Interoperability is a overall goal.

8 Summary

TinySEP takes advantage of two successful concepts of the software engineering: the driver concept and the signal-slot model. Thereby, the high usability of the proprietary, monolithic systems and the high re-usability of encapsulated components of modular AAL software platforms are combined. TinySEP covers all important software layers of an AAL platform. We see TinySEP as a starting point for a evolutionary process to develop a compact AAL platform. TinySEP shall be compared in detail with the openAAL and universAAL project in future work. In order to test TinySEP in real scenarios, two normally inhabited flats were equipped with AAL hardware. The AmICA WSN sensor nodes were chosen for the hardware. Currently, TinySEP is extended with methods of the Virtual Platform concept to enable early simulations under real conditions.

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Telemedical ILOG Listeners: Information Logistics Processing of Telemedical Values Using CEP and HL7

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Abstract. Optimal healthcare supply today relies extensively on the usage of technology to reduce the emerging costs and ensure high quality standards. Especially telemedicine, as a technology that offers the chance to optimize medical data transfer, is regarded as the promising strategy. As a result of the all-encompassing interconnection of healthcare sources, the actors like physicians are confronted with a growing amount of information, also known as information overload. Therefore we propose a new approach, according to the principles of information logistics (ILOG). Based upon complex event processing (CEP) we investigated the concept of Telemedical ILOG Listener (TIL) to process telemedical events in a very modular way. A telemedical event includes the medical data, attributes necessary for CEP and attributes to represent the dimension of ILOG. To standardize the representation of telemedical events we introduce the HL7 Telemedical Event Format.

Keywords: ILOG, CEP, Telemedicine, HL7.

1 Introduction

The work of physicians and other stakeholders in healthcare is based upon gathering information from different sources for medical decision making. Lack of adequate information could lead to inefficient medical treatment or to erroneous decisions [1]. The usage of Information- and Communication Technologies (ICT) like electronic health records or medical sensors is considered to be essential to optimize the flow of information and also to address the three main issues in today's healthcare supply:

1. The demographic change amplifies the need for new concepts of medical supply.
2. Many countries are at risk to suffer of undersupply of medical attendance in rural areas.
3. The economic structure in healthcare is out of balance.

Especially telemedicine is accepted as a research area which delivers concepts and technologies to solve the problems shown above. Telemedicine allows for communication between healthcare professionals and patients over distance. One example: The measuring of blood sugar concentration. The patient would send his values in a predefined interval to the physician. Considering the number of patients of a physician this would amount into an unmanageable number of messages. Most of these messages won't be related to a critical situation like hypo- or hyperglycemia, which means that it is irrelevant information from the physician's point of view.

The different possibilities to interconnect stakeholders and data sources in healthcare result in an unmanageable amount of information. Physicians therefore complain about the problem of information overload, which means that the information processing requirements exceed the information processing abilities [2, 3]. Three aspects one should bear in mind when talking about information overload: The **quantity** of information duplicates every 19 years [4]. Also the **time** for searching and processing medical information is very limited. Searching for information should be limited to 30 seconds to be acceptable for a physician [5]. The **characteristics** e.g. the complexity of medical information changes with the progress of medical technologies, so physicians need profound data processing abilities [6]. Approaches aiming to solve the problem of information overload in telemedical scenarios at first have to reduce the amount (quantity) of data. Second, the time for acquiring information has to be reduced by distributing relevant data along levels of escalation. One example: Depending on the event/emergency level, the nursing service is called first, before the physician will be informed. The characteristic of information is also a result of the particularization and diversification of telemedical applications. Hundreds of different telemedical applications using different data formats for different telemedical value types should get aggregated in a standardized manner. Existing approaches for intelligent medical data transfer and processing are highly customized to use-cases, like e.g. measuring the blood sugar concentration. Different applications will describe the same vital sign in different data formats. An integration of ILOG concepts, which implies to deliver the right information at the right time to the right place, doesn't really exist [1, 7]. The result is that there is no possibility to aggregate information from different telemedical sources to more significant information.

To enable the development of new approaches, which solve the problems shown above, we are investigating into a new approach named Telemedical ILOG Listener (TIL) using complex event processing and HL7 V3 to transport and process telemedical data according to the principles of ILOG [8, 9]. Corresponding to the high level definition of CEP as „…anything that happens, or is contemplated as happening", every vital sign produced in a telemedical scenario can be interpreted as an event [8], in the following named telemedical event. A TIL is a build block which encapsulates the logic to process one specific type of telemedical event e.g. blood pressure. The logic focuses on the recognition of critical situation, like an increase of blood pressure values. The input and output of a TIL is standardized using HL7, a widespread international standard for data exchange in the healthcare sector [9]. So, the transportation of highly distributed telemedical events can be optimized by standardizing their description using HL7. Based on it we are defining a message format which includes all parameters necessary for CEP and information logistics dimensions like time and place. In the following we'll focus on the definition of the concept behind Telemedical ILOG Listeners and we'll give a broad overview about the initial implementation efforts.

2 Motivating Use-Cases

We chose two use-cases as a basis to define and, at a later time, evaluate the concept of Telemedical ILOG Listeners. The use-cases reflect common health issues in Germany and most of them are also widespread worldwide.

2.1 Telemedical Monitoring of Cardiac Insufficiency Patients

In Germany, more than 1.600.000 people suffer from cardiac insufficiency. Due to the aging society, this tendency is increasing. In common parlance, cardiac insufficiency refers to a reduced pumping capacity as well as disturbed filling of the heart. The symptoms may include irregular heartbeat, tachycardia, hypertension, and water retention. Deficient therapy may lead to continuously reduction of the capacity of the cardiovascular system. Early and permanent medication is therefore essential for long life free of complaints. The following two parameters play a basic role for the monitoring:

- Weight: Changes in weight is an important indicator for water retention in the lungs and limbs. Especially the weight is subject to fluctuations, which is caused amongst others by certain medicine (e.g. diuretics). Left ventricular insufficiency often causes pulmonary edema, while right ventricular insufficiency encourages water retention in the limbs.
- Blood pressure: A significantly increased blood pressure, especially in combination with weight gain can be a sign for an aggravating cardiac insufficiency.

2.2 Monitoring of Sports by Patients Having Hypertension

Hypertension (high blood pressure) is worldwide one of the most common chronic health conditions. In this context, exercise is a basic instrument for a therapeutic modification of the lifestyle. In many cases, physicians will prescribe a therapy combining medicine and sports. The choice and control of intensity of sports applied as intervention mechanism against hypertension requires intensive monitoring of the following vital parameters:

- Blood pressure: The measurement and evaluation of the blood pressure value, considering its development, is the most significant vital parameter for optimizing the therapy.
- Pulse: Observing the pulse is also vital, especially when certain heart rate modulating drugs are prescribed. A simple, though little precise formula for determining the optimal pulse is: “180-Age”.

3 Related Work

The ongoing work is related to two research areas: ILOG is the central aggregator with its metaphor of transporting and filtering information in an intelligent manner. CEP is a promising technology for a fast, on-time processing of data.

3.1 ILOG

At present ILOG is viewed as detached research area to deliver the right information, in the right format at the right time to the right place [7, 10] and is partially used for information filtering or with context-models to optimize communication in the healthcare domain [1, 10]. Dinter and Winter give also a definition for information logistics as "the design, control, execution and control of all data flows…and the storage and post processing" [11]. It's a more organizational/data flow driven point of view. Haftor et al. give a broad overview of the state-of-the art research in information logistics by analyzing 102 scientific publications [12]. There are four active research directions in which user-demand-based information supply is the dominating one, advanced by the Fraunhofer ISST and also focused within this paper.

Information logistics is also strongly related to the topics of information overload and information need. According to Wilson and others information overload expresses „that the flow of information…is greater than can be managed effectively“ [2, 3]. Wilson emphasizes that the situation is not only caused by an improvement of technology but is also related to organizational, personal and external factors. There is not only an increasing amount of information which one can query (pull), e.g. scientific publications or journals but also an increment of channels for a proactive information delivery (push) [2, 3]. An intelligent information supply requires also a clear definition of information need. Line distinguishes five subcategories: Need, want, demand, user, requirement [13]. It's important to give a clear distinction between need and demand. The former describes all pieces of information which are needed to answer a given question und the latter the amount of inquired information which are assumed to be useful to answer a given question [14].

3.2 Complex Event Processing

The link between CEP and ILOG is given by Chandy by mentioning that „Disseminating and distributing is also about getting the right information to the right consumers at the right time.“ [15]. The basics of CEP were developed and defined by Luckham, Chandy and Bates [16, 17, 18] as „…an object that is a record of an activity in a system“. Hripcsak et al. were among the first researchers who combined the abstract concepts of HL7 with the term events which they call clinical event monitor (CEM) [19]. The CEM monitors the clinical situation of a patient and triggers the delivery of a message to a predefined recipient. The knowledge necessary for the decision for triggering the message is formalized using the Arden-Syntax which is also part of HL7. Hazlehurst et al. extended the concept in their implementation MediClass [20]. They analyzed HL7 CDA documents to recognize clinical events. Neither Hripcsak nor Hazlehurst give a definition for a general messaging format based on HL7 which could be used in CEP. Furthermore, the idea of intelligent information transfer using ILOG isn't present in their concepts. A detailed overview about open questions and the current state of research in CEP is discussed in the Dagstuhl Seminar on „Event Processing“ in 2010 [15]. Actual research in combining CEP and HL7 is covered within the development of Stride „The Stanford Translational Research Integrated Database“ [21]. Stride is some kind of data warehouse with over 100 million of data entries, e.g. diagnosis or laboratory results. One can query the stored data to answer a given question or use trigger to get informed when a given pattern is fulfilled. Weber gives a first impression how Stride could be used together with Esper, an event processing engine, to process health data [22]. The ongoing work of Weber and other researchers at the Stanford University aims to establish a better integration of HL7 and CEP.

3.3 Alternative Scientific Approaches

There are two important research areas one should take into account when talking about possible solutions for an intelligent information supply and filtering in telemedicine. At first there is the ongoing research on clinical databases and database management systems e.g. Stride „The Stanford Translational Research Integrated Database“ [21]. One extension are data streams for real-time processing of data like shown within STREAM [23]. Another research area is the field of agent-based systems, defined as “a system that perceives its environment and acts upon the information it perceives” [24]. Different kind of agents could be aggregated to a network called multi-agent system. Both databases or data streams and agent-based systems could be used to filter information but the structure of information isn't standardized, developed concepts are not that modular and they don't take ILOG into account. Therefore many papers in both research areas give an outlook on using events and event based processing for real time data optimization.

4 Information-Logistical Processing of Telemedical Values Using CEP and HL7

Bearing the three aspects of information overload in mind, one has to compete against the problems of quantity, time and characteristics of information. Like mentioned under related work there is a lack of valid approaches for which reason we are introducing the concept of Telemedical ILOG Listeners (TIL) to be able to process telemedical values in the sense of telemedical events. The concept will include solutions for the following problems or requirements [25]:

- A method for generic processing of telemedical values is needed. Therefore the concept has to include a general description of these bearing in mind the ability to process CEP and ILOG.
- The monitoring of telemedical values produces a high amount of data. The importance of a particular value depends on the order and also the dependency between different types of telemedical values. According to ILOG principles, a

physician or any other healthcare provider should only be informed if a telemedical value is important so that the amount of information can be reduced.

- Telemedical applications are highly distributed in the sense that every telemedical value has its own telemedical application and client. Thus the concept has to aggregate data from different sources to facilitate monitoring for the physician or any other healthcare provider.

Designing the approach of Telemedical ILOG Listeners requires a definition of basic building blocks. Etzion defined those for general purpose event processing [26]. We extended his work to be able to process telemedical events like shown in figure 1. Important building blocks regarding to the following work are marked with dashed lines. Within this paper we cover especially the definition of the conceptual design of Telemedical ILOG Listeners.

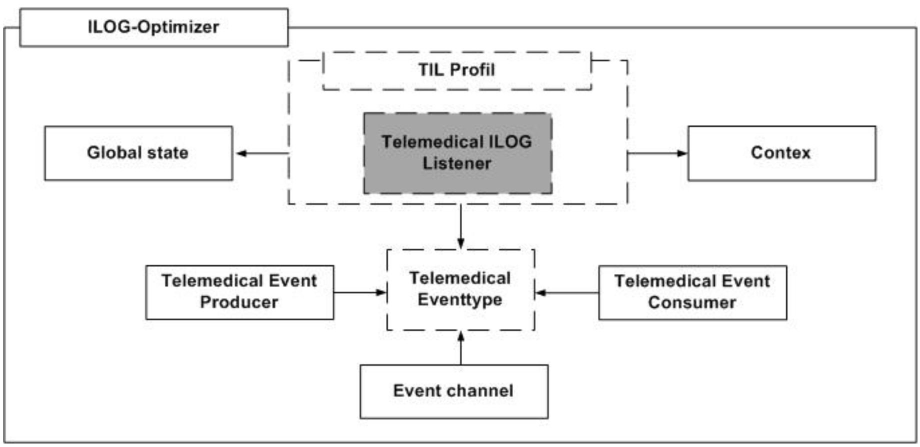

Fig. 1. Building blocks for the conceptualization of telemedical event processing based upon CEP

4.1 Architectural Overview

Figure 2 gives a broad technology independent architectural overview of how communication of telemedical values could be optimized using the concept of Telemedical ILOG Listeners. At the bottom we have different kinds of telemedical applications and sensors which generate telemedical values, like blood sugar concentration or the blood pressure. Today, in the majority of cases, these values are enveloped in a proprietary data format. This implies that a recipient has to use a specific client and also inhibits the potential for a high level aggregation of different telemedical values. Even though there are some applications using HL7 there is a lack of information to use this messages for CEP and ILOG. Therefore we are developing a message format based on HL7 called HL7 Telemedical Event Format. Not only the medical data could be described with this message but also ILOG parameters to represent the time or parameters necessary for CEP, like the description of dependencies through events.

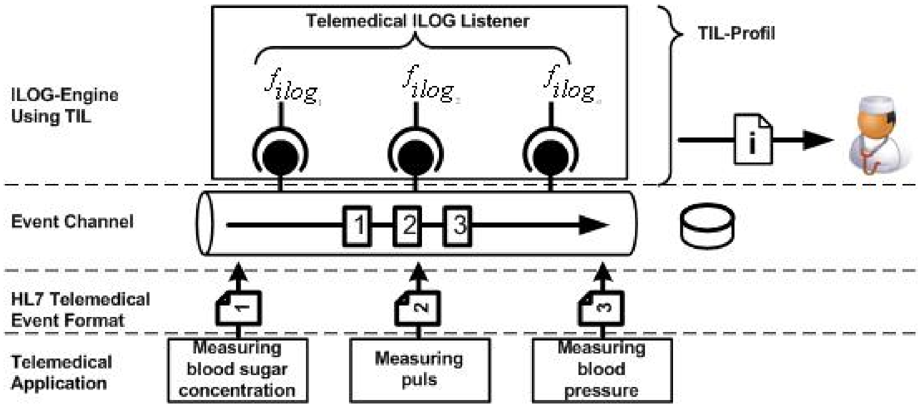

Fig. 2. Architectural overview for processing telemedical values under information logistics principles

The event channel layer in figure 2 should be some kind of intermediate e.g. a bus, event stream or event cloud to collect the incoming telemedical events enveloped in the HL7 Telemedical Event Format. The processing of them is done at the top using some kind of engine. Related to the topic of CEP we propose the usage of a well-established event processing engine like Esper [27]. For sure some work has to be done to integrate the concepts of TIL, TIL profiles and telemedical events. A TIL is some kind of event processing agent (EPA) which analyzes a set of telemedical events to detect patterns of interest. The crosslinking of different TILs in terms of an event processing networks (EPN) for a specific patient is called TIL profile. Next we'll give a detailed description of the concepts shown above.

4.2 Telemedical ILOG Listeners (TIL) and Profiles

Investigating solutions for solving the problem of information overload in telemedical scenarios means to reduce the amount of information. So, one has to develop concepts to process information in an intelligent way. Like proposed within the ILOG community the right information should be transported at the right time to the right place. Regarding to the architecture mentioned in the previous chapter there is a need for some kind of intelligence or engine to do the job. Having a look at the related work there are some good but specific solutions, most of them related to agent based systems or the field of databases. The specificity of the solutions results in very monolithic implementations which doesn't take the real situation of high distributed information suppliers into account.

Therefore we propose the usage of complex event processing. Why is CEP a probate technology for ILOG processing in telemedicine? Every value monitored by a telemedical application is some kind of event. This event is related to additional information like the time of generation or the telemedical value itself. This information normally will be transported to a receiver e.g. a physician. As a result a lot of information has to be analyzed by the receiver. To reduce the amount of information overload mechanisms needed to transport, aggregate and filter information. Also the consideration of the history and order of telemedical values related to an abstract time axis is important. The concept of CEP allows for aggregating, filtering and building causal relationships of events [18]. Also time could be taken into account. Within CEP we have the definition of event processing agents (EPA) and events processing networks (EPN). An EPA is something that "monitors an event execution to detect certain patterns of events" [18] like drawn in figure 3 (left side). It consists of a set of inputs and outputs between which one has to define the logic to process input data and send the result to the output side.

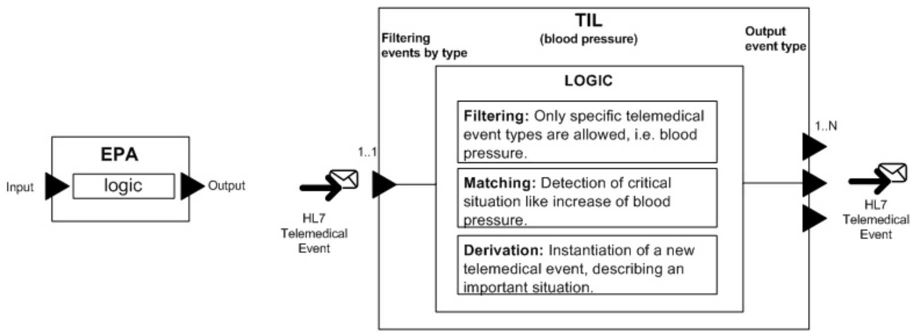

Fig. 3. On the left site there is the basic structure of an EPA and on the right site the definition of a Telemedical ILOG Listener, based upon the EPA definition

An EPA is a very generic and modular way to encapsulate knowledge to process data. Therefore we investigated the concept and definition of Telemedical ILOG Listener (TIL), which is *some kind of event processing agent, specialized for processing one type of telemedical values* e.g. blood pressure events. On the right side of figure 3 we have drawn the specialization of the EPA structure, that is:

- Input: A TIL is highly specialized on the processing of one telemedical event type. Therefore the definition contains only one single input connector.
- Logic: Within the logic one has to formalize the rules to process the incoming telemedical events. According to Etzion processing is a three step procedure [26]: First, one has to get rid of unimportant events by filtering them. Second, within the remaining events one can define rules and pattern to detect interesting system state or situations. Third, some kind of result has to be derived as an output to the rest of the world.
- Output: The definition of TILs contains more than one output connector. Depending on the matching and derivation process there is more than one possible outcome.

Using event pattern and other kind of rules allows the definition of constraints, which enables a TIL to fulfill task like aggregation, filtering or observing the history of events for instance blood pressure increased over the last 10 events. In table 1 we give a short overview of the most important operators a TIL has to take into account to be able to process telemedical events.

Table 1. Important operations a TIL should take into account

Operator	Description
DURING	Both the blood pressure and the pulse decrease during the interval $I[T_1, T_2]$.
AFTER/ BEFORE	x seconds after the decreasing of blood pressure the pulse decreases also.
OR, AND, NOT	Blood pressure higher than x AND weight smaller than y.

Using TILs results in high modularity because one can reuse a TIL in every telemedical scenario in which a similar telemedical question arises. This reduces cost and time investigation in the development of ILOG infrastructures in telemedicine scenarios. Another typical requirement in monitoring telemedical values is the correlation of different types of telemedical events e.g. blood pressure and weight. A TIL profile is some kind of event processing network, thus a concept to organize EPAs "into networks to communicate with one another" [18]. The basic structure is shown in figure 4.

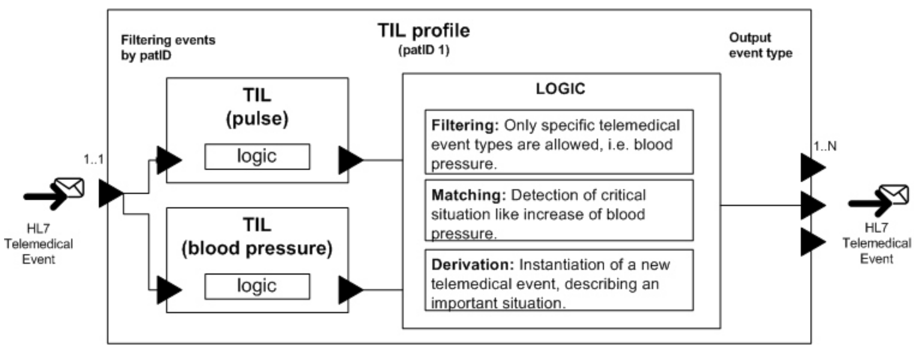

Fig. 4. Basic structure of a TIL profile for a patient with ID 1 and two TILs for processing blood pressure and pulse events

A TIL profile is optimized for a single patient respectively a given question e.g. *blood pressure > x AND weight > y* is highly related to the patients' medical situation. Therefore at first the profile has to filter all telemedical events that are not related to the corresponding patient of it. Within a profile one can define several TILs, depending on the medical situation of the patient and the according telemedical events. Combining the output of two different TILs is also done by using the operators mentioned in table 1. In the majority of cases every telemedical event is produced by its own telemedical application. Therefore the HL7 Telemedical Event Format is required to harmonize or standardize the communication (chapter 4.3). To process events a piece of software called event processing engine (EPE) is needed. A lot of open source and commercial EPEs are available. They differ from the algorithms used to fulfill the operations mentioned above. In chapter 5 we give a brief overview of an evaluation of two event processing engines and first implementation efforts.

Referred to the motivating use-case “Monitoring of sports by patients having hypertension” this means that two TILs have to be defined one for blood pressure and one for pulse. Probable these two values will be measured using two different sensors or applications in general. Dependencies between the histories of events are expressed with the usage of a TIL profile defining e.g. that a decrease of pulse and blood pressure should cause a new event to inform a physician.

4.3 Telemedical Events and HL7 Telemedical Event Format

Within the introduction we mentioned that the characteristic or complexity of information is one reason for information overload. Furthermore the distributed characteristic of telemedical application inhibits an overall processing of telemedical values to reduce them. Therefore we need to standardize the envelopment of telemedical values so that: 1. The telemedical value is included and described in a syntactical and semantic form. This allows algorithms and client programs to operate with the data. 2. Parameters for complex event processing could be attached. 3. Information logistics dimensions like time parameters could be included.

Part of our approach is the usage of telemedical events defined as a *measurement of a telemedical value and an instance of a telemedical event type, formatted in the HL7 Telemedical Event Format [28]*. The basic structure of a telemedical event is its underlying telemedical event type that is a *template defining basic attributes that every telemedical event of a specific vital sign has to satisfy*. The investigated basic model of a telemedical event type is shown in figure 2. We distinguish four segments: The type segment covers attributes which describes the kind of event type. In the processing segment all attributes necessary for ILOG and CEP processing are included. Data like a blood pressure value has to be written into the medical content segment. Last the payload-segment allows adding instance specific attributes.

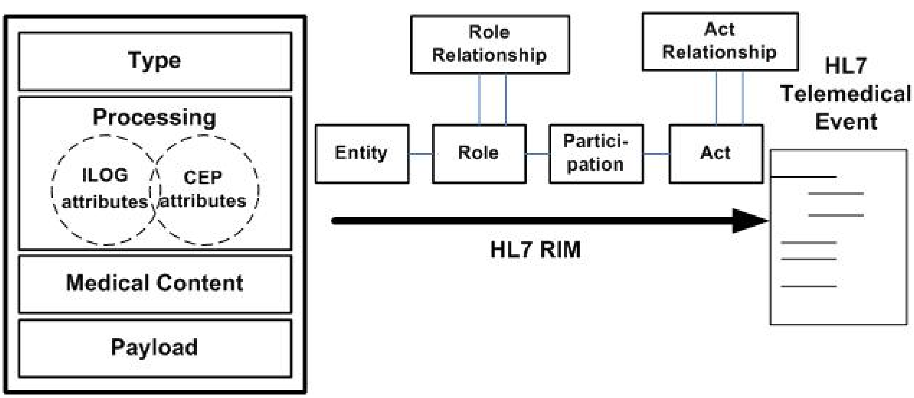

Fig. 5. Definition of the telemedical event type (left) and derivation of HL7 Telemedical Event

With respect to previous work of Luckham and Etzion [18, 29] there are some common parameters necessary to process events e.g. time, eventID, producer, causality. Especially time is important also for ILOG processing. One has to distinguish time on a semantic level into the time of generation, time of arrival, time of processing etc. From the ILOG point of view there are also parameters like the receiving application or person. These parameters and data have to be taken into account while defining the structure of a telemedical event type.

The following work is an iterative process to ascertain necessary attributes for ILOG and CEP processing as well as deriving the HL7 Telemedical Event Format. Latter is the XML based HL7 V3 representation which is based upon the HL7 Reference Information Model (RIM). Existing definitions like HL7 trigger events have to be analyzed and could probably be used as a basis for the HL7 Telemedical Event Format. Related to the motivating use-case "Telemedical Monitoring of cardiac insufficiency patients" two different instances of the telemedical event type have to be covered. Primary both instances will differ in the usage of the medical content segment. Also the type segment will differ in the type attribute – one instance will be referred to a weight value event and one to a blood pressure event.

5 Usage of an Event Processing Engine to Process Telemedical Events

5.1 Validation of Two Event Processing Engines

The processing of events requires an event processing engine (EPE). The market today offers a bunch of EPE products by well-known companies like SAP, Microsoft and IBM but the functionality between the products differs a lot. Therefore one has to assess the requirements for the choice of an EPE very well:

- Open-Source: To be able to extend an existing EPE to the requirements of telemedical event processing one should be allowed to modify the source code.
- Costs: To force a wide usage of telemedical event processing the end users costs should be as low as possible. So engines should be preferred that are free of charge.
- Formalism: The range of functions and formalisms of an EPE depends on the algorithms on which the engine is based upon. The engine especially should be able to process temporal relations between events.

According to the requirements shown above the authors evaluated Esper [27] and Etalis [30]. The result was that Esper fits most of the requirements and is easier to extend to the concept of telemedical event processing. Esper is an open source solution which is administered by EsperTech under the GPL 2.0. There is an implementation available for Java and .NET, so that it's easy to integrate it with existing Java applications. The input and output to or from Esper is done via CSV, XML, databases, Java Message Service (JMS) or HTTP requests. The support of XML allows an easy integration of the HL7 Telemedical Event Format. To process events Esper provides a lot of functions like sorting, filtering, correlating, aggregating or extracting. To formalize what a relevant event is, Esper supports the usage of event pattern matching and a Event Query Language (EQL) whose syntax is related to the SQL standard. From an algorithmically point of view Esper uses non deterministic automatons. To process event streams the usage of delta-flow networks is preferred. Performance tests have shown that Esper is able to process 500.000 events per second on a machine with two dual core CPUs with 2 GHz. The system scales horizontally, which means that the performance increases linear to the performance of the CPUs.

5.2 Implementation

Initially the authors implemented a first version of the HL7 Telemedical Event Format based on the event processing engine Esper. In figure 3 we show the way of communication. On the patients site some kind of device or software produces a telemedical event which gets transported through a JMS channel. JMS helps to avoid a loss of events in cases that the engine is overloaded. Overload would lead to a rejection of events. Afterwards the Esper event processing engine processes the incoming events and generates, in cases that a pattern is fulfilled, a message for a recipient on the physicians' site.

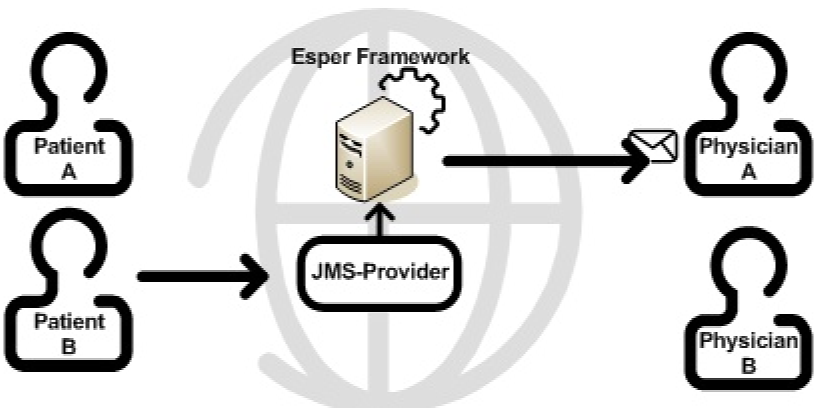

Fig. 6. Communication of telemedical events

In the following we will provide some example queries to filter and process events within Esper using the event processing language (EPL). Having EventA (weight) and EventB (blood pressure) one can build the queries shown below. To select all events of EventA with a value heigher than 80:

```
SELECT * FROM EventB (value > 80.0);
```

Esper also allows the definition of windows, which is a count based or time based limitation of events e.g. the last three events or all events in the last five minutes:

```
SELECT *, count (*) as Amount FROM EventA.win :
length(3);
```

Using the operators sum(value), avg(value), min(value) und max(value) one can calculate the sum, the average, the minimum and the maximum within a window of events:

```
SELECT name, count(*) AS Amount, sum(value) AS Sum, avg
(value) AS Average, min(value) AS Min , max( value ) AS
Max FROM EventA GROUP BY name;
```

In addition to the EPL queries Esper also supports event patterns as follows:

```
EVERY (a=EventA(value>120/80)OR b=EventB(value>80))
```

Event patterns and EPL could get assembled like shown below:

```
SELECT a.value, b.value FROM pattern [EVERY(
a=EventA(value>120/80) OR b=EventB(value>80))]
```

6 Conclusions and Outlook

Within this work we showed how the concepts of ILOG and CEP could be integrated and used to optimize the transfer of telemedical values. The definition of Telemedical ILOG Listeners enables one to build solution for handling the aspects of time and quantity within information overload. TILs are modular building blocks to filter, match and derive telemedical events. In this way, we will be able to fulfill the requirements in healthcare to monitor telemedical values with the least amount of information overload, in accordance with the principles of ILOG. With the investigation of the HL7 Telemedical Event Format we propose a mechanism to standardize the transportation of telemedical events in distributed telemedical scenarios.

The implementation of telemedical events and TILs requires an examination of event processing engines. They are the basic toolkit to process events and their abilities and functionalities depend highly on the underlying algorithms. Therefore we evaluated two solutions, resulting in a decision for Esper. From an implementation point of view, we are able to communicate a first version of telemedical events to the Esper EPN and processing these. The next step will be the extension of the EPN with the concept of Telemedical ILOG Listeners and TIL profiles. In parallel, we will discuss the evaluation of the concept, using the use cases described above. Further research is needed, especially in the field of structuring telemedical events and in the field of integrating context. We believe that using ontologies or taxonomies could be appropriate concepts for structuring telemedical events. In the area of context some work has been done for the health care domain. One has to verify whether the existing concepts fit together with the idea of TIL and ILOG.

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Part VI:
Interaction

Context Management for Self-adaptive User Interfaces in the Project MyUI

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Abstract. Good Human-Computer-Interfaces are necessary for an uncomplicated and reasonable use of software and devices, but depend heavily on the special capabilities of the user. Because it is nearly impossible for a "universal" design to fit to the very broad set of different persons, the appearance and behavior should be customized to the individual user. Current approaches are trying to give users the ability to customize the user interface by providing them detailed configuration abilities, which consumes a lot of time and is hard especially for older people. Also difficulties arise for older people and people with certain limitations, because their capabilities change with aging or with advancing deceases. This makes a row of subsequent adjustments to the Human-Computer-Interface necessary. The MyUI project funded by the EU tries to develop a framework to overcome this problems by using adaptive interfaces.

1 Introduction

The population of Germany becomes older because of the demographic change. Studies of the federal statistical office show that there will be approximately 33% more people aged 65 years and older living in Germany in 2030. Furthermore the average life expectancy stays rising. [1]

The number of people with sensory, cognitive and motor limitations originating from the normal aging process or diseases like stroke will grow. The share of disabled and handicapped people in Germany was 11% in the year 2009. [2]

At the same time the digitalization of the population is progressing at huge steps. In the year 2011 around 75% of all Germans are using the internet. Even in the group of people aged 50+ the share is 52.5%. [3] Digital tax declaration, informal communication with public authorities per email or the uncomplicated and fast communication with the family – each one of these can be done with web-enabled devices over the internet.

Unfortunately most of the user interfaces of these devices are not suited for people with disabilities or handicaps. Furthermore the non-intuitive handling and long training periods reveal problems for most elderly people. Most software is still engineered towards younger generations which results in additional usage barriers like e.g. too small fonts or symbols. [4]

The solution could be devices with user interfaces especially engineered towards the requirements of people with disabilities. Problematic would be the huge number of different disabilities people can suffer, different intensities and characteristic of the same disability for multiple people and multimorbidity.

In the following paper we present a possible architecture and the underlying data model of the EU-funded project MyUI. The goal of this project is to develop a framework for adaptive user interfaces, which constantly adapt themself to the requirements of people with handicaps and disabilities. This self-adaptation of the user interface happens permanently with the help of a user profile which captures all limitations of a person and by integrating context data of the user.

2 Basics

2.1 Adaptive Systems

An adaptive system is a system which adapts itself to the requirements of a user. [5] This adaptation happens on the basis of the interaction between the user and the system as well as his environment. Underlying is a model of the user which can change over time as the system discovers more knowledge about the user. Paramythis et. al. [6] divides an adaptive system in three basic steps:

- Afference
- Inference
- Efference

The first step collects data from observations of a user dividing between implicit and explicit data collection. While the user isn't directly involved in the implicit data collection, for example with the help of sensors, the user is actively involved in the explicit data collection, e.g. with questionnaires. During the "inference" a user model is created or adopted from the data captured during the "afference". In the last step it is decided how the user interface will be adapted.

2.2 Context

Context commonly refers to every information used to characterize the situation of an entity. Such an entity can be a person, a place or every other arbitrary object which is relevant for the interaction between the user or the application – including the application and the user itself. [7]

This information has to be available in a format that machines can understand.

3 Architecture

The following presents an architecture containing the user model, the context manager and the adaptation engine. The context manager manages incoming sensor data and adapts the user profile, which is an instance of the aforementioned user model, based on this data. The adaptation engine uses the user profile to create a user interface from interaction patterns.

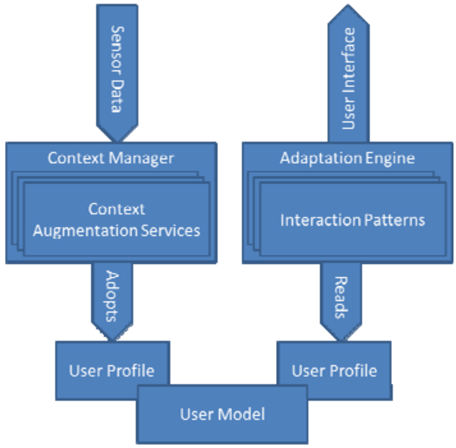

Fig. 1. Proposal for the architecture of an adaptive user interface

3.1 User Model

As described above the adaptive system decides based on the user model how the system is adapted to the requirements of the user. In order to support this process the description of the user has to be derived from the factors that influence this adaptation.

Considering an adaptive system which adapts to the limitations of a given user it can be concluded that these limitations have to be found before a suitable model of the user can be created. The questions of interest are which limitations arise from the natural aging process and e.g. stroke and whether these limitations influence the usage of web-enabled devices.

A study conducted by Smith, Norris und Peebles [8] for the Department of Trade and Industry in the UK showed e.g. that people decrease in size, joints become less flexible and the strength of the muscles decreases. Next to these motor limitations the study also investigated the sensory and cognitive capabilities. In the area of sight it has been found that the visual acuity of a person decreases linear with the age and that more light is needed to see clearly.

Based on this data a user model has been derived which includes limitations of the following abilities:

Table 1. MyUI User Model – captured capabilities and limitations

User Model Variable	Description
Visual Acuity	The ability to read small font sizes.
Colour Perception	The ability to differentiate between colors.
Field of Vision	Self-explanatory
Ambient Light	Light sensitivity
Ambient Noise	Noise sensitivity

Table 1. *(continued)*

Language Reception	Ability to understand written or spoken language.
Language Production	Ability to speak and write language.
Understanding Abstract Signs	Ability to understand abstract signs or pictograms.
Attention	Ability to handle multiple things at the same time, resp. focusing on something.
Processing Speed	Ability to process information fast.
Working Memory	Ability to remember an exact sequence of steps in a process and the ability to orientate in this process.
Long Term Memory	Ability to learn and remember information for a long time.
ICT Literacy	Ability to use modern information technology.
ICT Anxiousness	Describes the caution in the usage of modern information technology.
Speech Articulation	Ability to speak.
Finger Precision	Ability to move the fingers precisely.
Hand Precision	Ability to move the hand precisely.
Arm Precision	Ability to move the arms precisely.
Contact Grip	Ability to touch things, resp. to control things by touching them.
Pinch Grip	Ability to press single buttons.
Clench Grip	Ability to hold object.
Hand-Eye Coordination	Ability to coordinate the movement of the hands with things seen.

To evaluate these capabilities a scale is introduced which contains an interval between 0 and 4 for all of the capabilities and limitations listed in the table, where 0 corresponds to no limitation and 4 is corresponding with a strong limitation.

The instantiation of this model for a given user can be done with the help of multiple assessments (explicit data collection) or during the usage of the user interface with the help of sensor data (implicit data collection). In the abovementioned data model the standard value for every limitation is set to 0 – no limitation.

3.2 Context Manager

The context manager contains the steps „Afference“ and „Inference“ from the aforementioned model of adaptives systems. The goal is to represent the current context in a way that the “Efference”-step is made possible.

The tasks of the context manager are the collection and derivation of information about the environment of the user, e.g. the brightness of the room in which the user currently resides, as well as the user itself. (“Afference”) Furthermore the context manager manages the instance of the user model for the given user and can adapt this instance. (“Inference”)

3.2.1 Afference: Collecting Sensor Information

As already stated in 2.1. one can differentiate between implicit and explicit data collection. Both types of data collection have to be supported by the context manager. The implicit data collection is hereby carried out by sensors which collect information about the user in an unobtrusive and transparent way. The problem is that single low-level sensor events cannot be directly used because they do not deliver enough useful information. This problem can be solved by connecting several low-level sensor events from different sensors to high-level sensor events. These high-level sensor events are reasonable accurate to change the instance of the user model.

3.2.2 Inference: Derivation of New Informations about Context and User

In order to derive new information about the user and his context different approaches can be used. According to Kobsa [9] rule-based approaches, probabilistic reasoning, data mining and other methods from the field of machine learning are suitable for the task at hand. Every approach has its individual advantages and disadvantes. Probabilistic methods for example are well-suited for the recognition of activities while rule-based approaches are easy to implement. To ensure a high flexibility the representation of the information inside the context manager, as well as the architecture of this component, has to be suitable for different methods. This can be achieved by a data-centered approach like the so called blackboard-architecture [10]. It is characteristically for this architecture that every kind of information (e.g. sensor events, derived information) is made available to every other component by a central component called the blackboard.

Inside the context manager multiple mechanisms for the derivation of new information are working next to the blackboard component. Each of these so called context augmentation services can implement different methods which can for example be used to change the variable “Visual Acuity” of the user model based on the measurements of a sensor for gesture detection.

The division between sensor/user model data and the implicit knowledge about the processing of these information inside the used algorithms and methods makes it possible to work with different methods inside the same system, as well as providing the ability of prototype-centered development.

3.3 Interaction Pattern

An interaction patter is a template for a given interaction situation in which a user interacts with the user interface. These interaction situations correspond to an abstract interaction process, respectively to an abstract description of the user interface like “Choose one element from a list of multiple elements”. A concrete application consists of a sequence of interaction situations. During the runtime of such an application these interaction situations are exchanged with corresponding interaction patterns.

Multiple interaction patterns can correspond to a given interaction situation, while each interaction pattern is suited for a specific set of user profile variables and given values for these variables. So each interaction pattern contains a description for which users it is suited.

3.4 Adaptation Engine

The adaptation engine contains the, Efference“ step in which a user interface is created for a given instance of the user model. The composition of the user interface is done by comparing the information of the user model instance to the information of each interaction pattern. For the comparison a score is calculated which reflects the fitting of the interaction pattern to the current user profile. The patterns with the highest score will be used in the composition of the user interface.

4 Data Model

4.1 Ontologies

In order to create a structured representation of the context, the user model and the sensor data MyUI is heading for an approach based on ontologies. An ontology is understood as a “formal, explicit specification of a common conceptualization”. [11] Ontologies are used to derive data structures, schemas as well as interfaces which provide access to the data saved in the format of a given schema. During the development of such an ontology the following characteristics have to be taken into account:

- The ontology has to be designed in a formal way so that it can be processed by machines.
- The ontology has to be reasonable for the task at hand. It should describe the problem domain reasonably well without containing too much information.
- The ontology represents the common understanding all of its users have about a problem domain.

4.2 User Model Ontology

In this chapter the single instances of the user model will be called a user profile. A specific value inside the user profile will be called a user profile variable.

In order to represent the data of a user profile the data model of the Resource Description Framework (RDF) has been chosen. RDF is a standard for metadata in the World Wide Web and is developed by a group of the W3C. In combination with extensions like RDF-Schema (RDFS) and the Web Ontology Language (OWL) it is the basic data model for many context management systems.

RDF describes things in the form of resources which can be divided in subjects, predicates, objects and statements. Statements represent a triple which, like a sentence in a real language, consists of a subject, a predicate and an object. Each resource in RDF is unambiguously identified by its Uniform Resource Indicator (URI).

In the user profile presented in this paper each capability, respectively limitation corresponds to a statement where the subject identifies a given user and the predicate identifies the capability of this user with the help of an URI. The object of the statement contains the assigned value for the capability. A set of statements with the same subject is the user profile of the user identified by the subjects' URI.

Which predicate are allowed for statements with a user URI as their subject and which values (objects) can be assigned to it, are defined in the user profile ontology. An overview of the possible predicates has already been presented in Table 1. Each variable in the above table can contain values between 0 and 4. Another possibility for values are also String-values or a value from an enumeration.

The resulting formalism is built up of RDF and parts of RDF-schema (concept- and property-hierarchies) and is derived from the data model used in OpenAAL. [12]

4.3 Sensor Ontology

The data model of the sensor ontology is used to support the „Afference" - the collection of sensor information. Each information about the user and his context has to be derived from the information provided by sensors. In MyUI it is divided between physical and virtual sensors. While physical sensors correspond to a piece of hardware, measuring things in the environment of the user, e.g. gestures, virtual sensors measure data about the usage of the user interface. Both types of sensors are modeled in the same way.

The basic principle behind this model is that all sensors detect sensor events. Such a sensor event is, like the data of the user profile, represented as a triple containing the URI of the sensor, a description of what has been measured and the measured value. This model has been derived from the method for Sensorstati described in [13].

Like the user model ontology the sensor ontology is also designed to be simple and easy to understand in order to support extensibility.

In addition to the pure capture of sensor events an instance of the sensor ontology has to contain metadata about the sensors in order to support the derivation of suitable information. For a combination of a RFID-reader and a RFID-transponder it is advantageous to include the following metadata in order to detect whether a specific person has entered a room:

- The RFID-transponder A belongs to person X, or is worn by person X, or is attached to person X
- The RFID-reader B is located in room Y

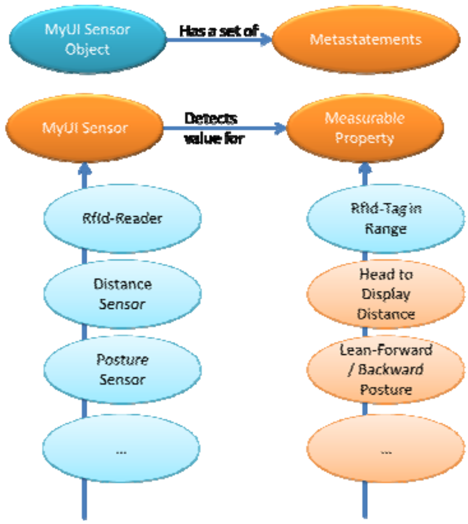

Fig. 2. Example of a simple sensor ontology in MyUI. As an example different types of sensors are modeled. The color orange describes an abstract concept, light blue specialized concepts and light green numeric values, strings or enumerations.

When the context manager receives the sensor event “RFID-reader B detected RF-ID-Transponder A” it can now infer that “Person X entered Room Y” by incorporating the abovementioned metadata.

5 Outlook

5.1 Explicit Data Collection with Cognitive Games

Cognitive games are derived from cognitive tests or challenges, which have a game-like characteristic. These tests or challenges are used to measure the cognitive capabilities like the memory, the attention, the reaction time or the ability to create associations. They can also help to reduce cognitive deficits. Some cognitive tests can help to diagnose for example ADHD, schizophrenic disorders or Alzheimer’s disease. The cognitive tests contained in the Cambridge Neuropsychological Automated Test Battery (CANTAB) can be used to identify 100 disorders at an early stage. [14] [15]

In order to motivate the user to perform these tests on a regular schedule, MyUI provides these tests in the form of games, for example with different backgrounds or other stimuli. After playing the cognitive games the user receives his achieved score which allows him to keep track of his success or failure.

An example for the measurement of visual attention is the Trail-Making-Test [16], which is used in the neuropsychology. There are two different versions of this test: in the first version the user has to connect 25 numbered circles on the screen. In the other version the user has to connect alternating numbers between 1 and 12 and letters from A to L (1-A-2-B-3-…). The faster this challenge is solved, the higher is the resulting score of the user. The time the user needs to solve the challenge is measured in milliseconds and based on normative data, age, gender and education the cognitive capability of the user is categorized.

Administrative instructions for the game are given to the user via speakers or through instructions displayed on the screen.

In the above example of the Trail-Making-Test the user profile variable for "Attention" would be adapted based on the results the user achieved while playing the game. The normative value would be converted to the value 0 of the user profile variable. Depending on the cognitive game and the interval of the normative scale for the game thresholds for the values 1 to 4 of the user profile variables would be identified.

5.2 Evaluation

Prototypes of the system presented in this paper will be tested during a field study with elderly people and stroke patients.

The subjects receive challenges which they should perform under supervision. For this task a device with an adaptive user interface based on MyUI will be available to them.

Afterwards the subject will be asked about the user interface and their feeling about the adaptations with a questionnaire.

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RehaWeb - An Information System for Cardiologic Rehabilitation Assistance in the Third Phase

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Abstract. The RehaWeb system aims at motivating heart patients in rehab with a combination of social networking features, editorial contents as well as mobile support and monitoring. Hikes on selected routes can be planned with RehaWeb community friends. A smartphone application guides the way and collects vitals. All data is transmitted to the RehaWeb server, where it can be accessed as exercise diary by the patient and medical staff. The personal progress and other topics can be discussed with other user in the forums.

1 Introduction

Cardiovascular diseases constitute nearly 30% of the most common cause of death worldwide [33] [7]. In Germany, this group of diseases includes even 43.4% and has the highest proportion (14,5%) of all expenses of a class of disease [27].

Demographic change and the shortage of funds forced a rethink in health care. Already, the number of over 65-year olds in the population is at around 20%; in 2050 it is expected that one in three (33.1%) Germans are over 65 years old [26]. The professional medical care to the population here is a great challenge for health policy, particularly with regard to supporting chronic ill patients. Approx. 80% of all chronic diseases, however, are attributable to modifiable risk factors individually [34]. This underscores the incredibly high number of responsibility and obligation of every individual in society for preventive and secondary preventive care.

The efficiency of traditional rehabilitation after a hospital stay is largely occupied and recognized. This should then be carried further by the individual in the rehabilitation phase II learned strategies. Unfortunately, different studies showed that the constellation of cardiovascular risk despite curative treatment followed by rehabilitation one year after a clinical event, the initial level again approaches [30] [31] [17].

Help for trend reversal and a valuable addition to sustainable supply concepts in the field of Ambient Assisted Living may represent in the future by IT-based systems.

Similarly, in health care research is an increasing shift of medical services from inpatient to outpatient care is observed. This trend will increase even more the longer term. Coupled with the increasing desire of people to remain as long as possible in their own home environment and to be supplied, will increase the demand for new (even medical) services in the home environment.

Lack of exercise is the most important modifiable risk factor, followed by smoking cessation and diet [18] in relation to total mortality. Accordingly, physical activity represents a dominant, preventive approach to reducing morbidity and mortality.

Motivated by these recent developments, the Chair 4 of the Technical University of Dortmund and the Schüchtermann-Schillerschen Kliniken Bad Rothenfelde developed in the context of a two-semester project an online community that allows patients, even after the inpatient stay in a hospital, to follow continuous through lifelong learning (phase 3 cardiac rehabilitation) the latest standards of care and treatment procedures from home.

The main objective of this platform is to provide a social network for former patients to strengthen self-efficacy and increase the motivation to sustainable, health-promoting activities. Thereby the empowerment of patients through the exchange of experiences with others stands in the foreground. The network aims to strengthen the sustainable motivation and not falling back into old disease-favoring habits after the rehabilitation. A constant exchange with "like minded people" gives the users the feeling of one interaction and strengthens participation in physical activities to improve their health.

Through a central planning of hikes over the platform it is possible for the user, either with friends as well as with new contacts in the community come together and organize joint activities.

For documentation of measured values during the tour a mobile application for smart phones was developed as a communication tool. In addition, an ergometer training - with monitoring of vital data can be completed. All datasets can be stored in a personal area of the community and from there - if desired it will be redirected to the after treated physician and noted in the digital patient record.

The smartphone application offers the possibility to record additionally geographic data. These tracks can be fitted with pictures or comments and could be made available to friends as a route proposal.

The work is based on the results of the BMBF-funded project OSAMI (Open Source Ambient Intelligence).

This paper first introduced related work and afterwards discusses requirements and possible solutions to the system. The following sections describe the system and its architecture in detail. In Chapter 6 the evaluation and its results are described.

2 Related Work

There is already a variety of systems and applications which cover the individual areas of eHealth and Ambient Assisted Living. This begins with health communities and spans mobile support in any situation right up to the sensory acquisition of personal data.

Besides the well known social networks like Facebook, Friendster and the VZ-networks, which are focused on the general social networking of its members, many health-sector-specialized communities have evolved. In this context, e.g. Imedo [14] and VITACLIC [29] are mentionable. Both vendors offer the option to discuss active, as part of the community, on health issues or to exchange experiences and advice with each other. For expert answers to medical questions, a comprehensive medical dictionary is available and doctors are involved in the network.

Another important area in the context of IT-based assistance systems is the mobile support for health maintenance. There are numerous solutions that have been created to promote fitness. One example is SportsTracker [25], which provides a smartphone application and an associated community. Users can plan trainings or exchange experiences on the website. The application records the user's pulse in athletic activities if an appropriate pulse belt is available, as well as the distance covered using the GPS signal. The data can be viewed during and after the training session and can be uploaded to the website. There the training sessions can be managed, compared to other ones or shared with other users. Other similar projects are Smartrunner [24] and Runtastic [23], which also focus on sport and social networking, but yet not offer medical assistance.

At least a virtual assistance for training exercises is offered by the Mobile Personal Trainer (MOPED) [4]. This project not only records and analyzes data, but also focuses on motivation and guidance. A virtual trainer provides detailed instructions how to perform a certain exercise or gives acoustic navigation hints during a run workout. The measured pulse data directly influence those instructions. That way the user can be motivated to increase speed at low physical loading.

There are additional mobile concepts where the medical aspect has priority. Valrie Gay and Peter Leijdekker describe a smartphone-based sensor monitoring of a patient [10]. Devices such as ECG, accelerometer, oximeter and blood pressure meter send data on the person's constitution to the smartphone. This evaluates the data and can detect emergencies, such as falls or cardiovascular events and then transmits the patient's location with the help of GPS or other location-dependent data within an emergency call.

A project, still in the development phase, that joins both a community and the self-monitoring of vital signs, is Well.com.e [32]. It is especially designed for chronically ill patients and is to encourage their health-oriented behavior. This shall be done by the combination of self-monitoring, a community and a marketplace. Thereby the cardiovascular parameters are measured using a sensor system and are wirelessly transmitted to the platform. These data are interpreted and presented to the user in a secure area of the community. The community's main task is to support users in exchanging ideas to each other. The last component is a marketplace where appropriate products and services, derived on the recorded data, are offered to the user.

3 Requirements and Solution Approches

For the envisaged project RehaWeb it was necessary to meet various social, technical and medical requirements.

3.1 Social Requirements

- **Low entry barrier and accessibility**
  The target group Generation plus has little experience in dealing with modern media. To solve this problem, an age-appropriate user interface of the website [15] will be introduced and the special needs of mobile applications will be considered [12]. Furthermore, no special equipment - only a browser and a smartphone - will be assumed for the RehaWeb system, so that a fast entry is backed.
- **Convey overvalue at initial visit**
  In concrete terms, content which encourage participation, must be offered for unregistered users [16]. This point is met by a well structured portal that informs users by magazine content on relevant news in the field of rehabilitation. A forum offers the opportunity to follow discussions, a catalog of approved trails is directly accessible to the public.
- **Increase motivation to secure long-term use**
  The goal of Lifelong Learning - no falling back into old habits - will be fulfilled in a first point by ensuring the interaction between the users, and the thereby resulting mutual motivation. For this purpose, the RehaWeb community is based on user profile structures along the lines of social networks [22]. For each member, a new profile is generated which is filled with information from the owner, and can be linked to other profiles using a buddy system. For communication, private messages and forum areas as well as comment fields with assessment options are available. As an innovative concept, RehaWeb distinguishes itself in an integration of a trail system with an associated migration planner. The health community therefore includes the functionality to create and manage routes and to plan individual or group tours, which are supported by a smartphone application.
- **Building trustfulness**
  In the sensitive area of medical applications, the mediation of trust is a necessary prerequisite with respect to a high user acceptance [19]. For that purpose, actions concerning data security and safety as well as data privacy are revealed. In the medical field, individual consultations and the analysis of training sessions by medical professionals increase trust.

3.2 Technical Requirements

- **Achievement of data security and privacy**
  Sensitive patient data are subjected to high requirements of data security and privacy. To meet these criteria, patient data are transmitted via secure connections to the server and are stored in a database. Access to these data

is based on the RBAC principle [8] that ensures access only to authorized persons. A backup system prevents the loss of data and a resulting mistrust. Furthermore, the principle of informational self-determination is applied, the participant controls his personal data and its visibility at any time.

- **Dealing with unreliable data connections**
  Hiking in rural areas increases the risk of unreliable or nonexistent UMTS network coverage. To counteract this problem, the data of a smartphone supported hike is either submitted live to the server, or collected after the training session, depending on the settings. The navigation features of the smartphone application must be constantly available, even if the data connection is lost. That is why RehaWeb uses of offline maps.
- **Sustainable maintainability and extensibility**
  For the long-term success of the project, a continuous extension and adaptation to changing parameters must be ensured. As a result, open and well established standards are used in the development. This concerns both the used web technologies and the maps [13].

3.3 Medical Requirements

- **Supervised hiking and ergometer training**
  Core of the RehaWeb system are training sessions supervised by medical professionals. For this purpose, the smartphone application developed for the support of hikes, and the ergometer are connected to the community. Distinction is made between autonomous offline training and live monitored online training [3].
- **Recording of vital data**
  For the acquisition of physical constitution in the course of cardiac rehabilitation and prevention a broad spectrum of medical sensors is supported. These are pulse and ECG sensors in the mobile sector and additional blood pressure and SpO2 sensors in the ergometer training at home.
- **Preparation of training sessions**
  The data recorded in the course of training sessions is processed in order to support the analysis of the sessions by medical professionals or by the patient himself. To this end, a first statistic on the most important data is displayed on the smartphone after a completed hike. A detailed evaluation is offered in the private area of the community comprising an opportunity to generate reports for printing.
- **Avoid confusion for patients**
  In the area of eHealth applications, confidence and the sense of security are an important part [28]. For this reason, not all vital signs of a patient during a hike or an ergometer training are displayed. Particularly, the display of the ECG curve is reserved for medical professionals.

4 RehaWeb System

The RehaWeb system is divided into three areas: community, hiking, and domestic ergometer training (see figure 1). As the entry point, the community provides patients and interested parties editorial content around the topic of cardiac rehabilitation and in particular on the gentle endurance sport hiking. These articles, published by medical professionals, serve the users as a source of information about news and backgrounds, and thus motivates their active participation.

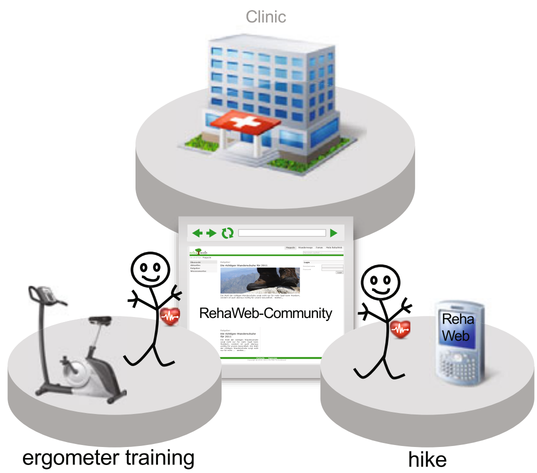

Fig. 1. The RehaWeb system

Full access to the functions of the community will be granted only after a registration. From now on, the user can use the typical features of a social network, where communication and interaction with other participants have priority. Through this approach the contact to like-minded people is eased for the patients and thus strengthens the motivation for sustainable rehabilitation.

Beside the well known functions of a social network, the RehaWeb community provides special features to meet the medical requirements. The main point is the planning of hikes. For that to happen, the user can select a tour from a list of trails in the region. Detailed information is deposited for each route (see figure 2), e.g. a brief description, photos, difficulty and the length of the path. Meters in altitude to be covered are given and an elevation profile is displayed, moreover the route is shown in a map to give hikers the opportunity to locate the track.

Registered users can indicate at any trail, whether they like the route, can provide details comments and can upload own pictures to it. After selecting a route, users can plan a hike. On that point, they schedule an appointment and then invite friends to participate. Thus, the planning and execution of hikes

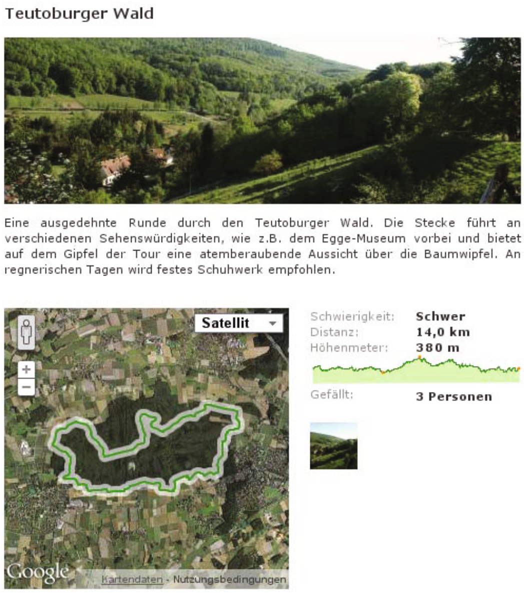

Fig. 2. Detailed information for a hike

becomes part of the social network. Virtual friends go hiking together and motivate each other in their rehabilitation.

An alternative to walking but also an entry into the home rehabilitation is the ergometer training. The RehaWeb community offers the possibility to design new ergometer exercises or to select from existing training plans. In those, the duration of the training and the time variable wattage is set by the user or by medical professionals, and can be adapted to the conditions of the patient. The wattage profile of a training similar to the elevation profile of a hike is displayed before the selection.

The results of workouts hiking or ergometer training can be accessed afterwards by the patient in the training diary of the community, or even live by authorized personnel during the recording. Figure 3 shows the results after the recording of an ergometer exercise.

Depending on the type of the exercise and the recorded values, maximum values of vital signs and different detail views are available to assess the condition of the patient in general and at various time points during the recorded training. In this example, the pulse curve and the assessment of the personal strain according to the Borg scale [2] are displayed as an overview of the entire training process. The pulse curve and the ECG waveform are in detail accessible.

The execution of a hike is supported by a smartphone application. A planned training in the community will be displayed in the smartphone application and all data preconditioned for the execution of the smartphone supported hike are automatically downloaded. The user can select whether a previously scheduled training should be performed, or an existing route in the nearby environment should be hiked, or a non routed hike should be recorded or if only vital signs should be monitored.

Fig. 3. Ergometer exercise

Figure 4 depicts the smartphone interface during the walk of a planned exercise. In order to orient themselves in the terrain, the hiker's current position, the route and the position is sketched in a map using GPS data by the smartphone's internal GPS receiver. The map data is copied on the phone and is thus also available if the phone has no signal to the cellular network. Thus, the amount of transferred data is minimized.

During the hike, the current heart rate and the still remaining distance is displayed. Furthermore, photos can be taken and Borg values can be indicated. In case of health problems, the patient can trigger an emergency call with the specified button.

To record medical data such as heart rate and ECG parameters, the smartphone application supports in its first implementation two chest straps, on the one hand the pulse belt Zyphyr Consumer HxM, and on the other hand the Corscience 1-lead ECG Corbelt: Event Recorder. Both communicate via Bluetooth with the smartphone.

If the phone is connected to the cellular network, the Borg, pulse, ecg and GPS data are transferred immediately to the RehaWeb server and can be accessed by authorized personnel directly after the recording. If no cellular network is

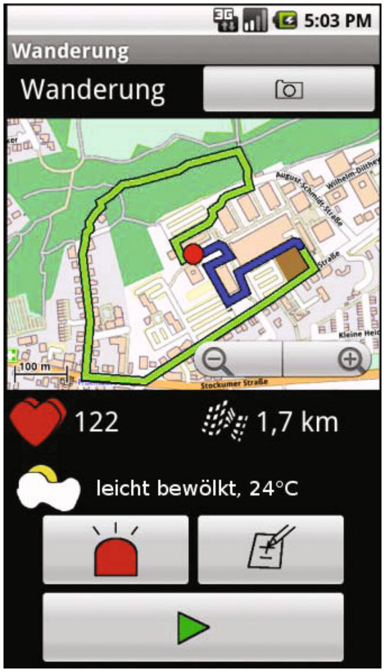

Fig. 4. Smartphone-supported hiking

available, the smartphone application stores the data and transfers them as soon as the link to the server is restored.

For performing an ergometer training, the selected training plan is transferred from the community page to the ergometer. During exercise, an overview containing data such as start and end time, the wattage profile and also the so far completed training workload is provided for the user. In addition, patients can specify their condition by Borg values. Due to this, patients can learn in conversations with the doctor to assess their physical working capacity without assistance from medical devices.

5 Architecture

The individual components of the RehaWeb-system are implemented using a layered architecture. One of the requirements for this was the usage of open and established standards.

5.1 Server

The server provides the functionalities of the community and the interface for ergometer trainings in form of a web-interface. Another task is the central data storage and processing and provision of a RESTful API [21] to access these data. The server component was developed in a service-oriented and layered architecture (see figure 5).

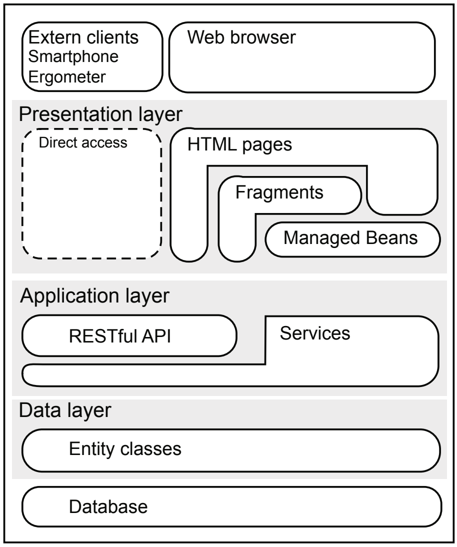

Fig. 5. The server architecture

The presentation layer creates HTML-code for display in the user's browser and prepares all needed data for this. This is realized using Java Server Faces 2.0 [11]. For display as well as processing data, the services in the application layer are used.

The services are developed using REST principles [21] [9]. They are stateless and wrap all communication with the database. Each service class is responsible for one type of resource and offers methods following the CRUD principle [20]. The RESTful API is implemented on top of these services and mostly addresses the limitations of HTTP and JSON [5] as transport format.

The data layer consist solely of entity classes, which represent a direct mapping of Java objects to database rows. This is done using the Java Persistence API [6].

5.2 Smartphone Application

The smartphone application collects vital and location data and supports the user's orientation in the terrain. Again, a layered architecture with a presentation, an application and a data layer was employed (see figure 6).

To fully exploit Android-specific features, the separation is not strict. In some situations direct calls from the upper to the lower layer are allowed.

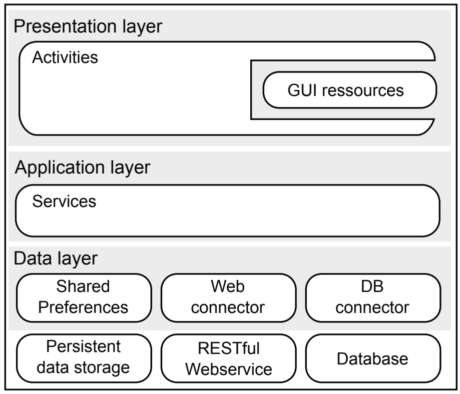

Fig. 6. The smartphone architecture

Within the presentation layer Android elements like Activities, Layouts and Styles perform the display of content and processing of interactions. This offers a clean separation between look and behavior [1].

To allow interactions during long-running operations, these are executed in the background. This includes communication with sensors as well as with the server.

The persistence of data uses Android-native APIs, too. These are Shared Preferences for singular data and the embedded SQLite database for data records following a defined schema. For communicating with the server, there are also special web-connectors.

6 Evaluation

After the functional tests, an evaluation with 12 subjects was carried out, which should examine the acceptance of the system and the benefits for the target group as well as the ergonomics of the user interface. The subjects were 28-67 years old.

The possible target individuals of the RehaWeb system can be divided roughly into two groups. Patients in the cardiac rehabilitation, where participation is recommended directly, and generally interested persons who took notice of the platform through secondary sources. The first group may not be practised in dealing with the media internet and smartphone, and will always be briefed by professionals in the platforms usage. Since the second group sign in independently in the RehaWeb community, a skilled handling of web applications can be presupposed. In order to achieve the most realistic test setup, the subjects were also divided into two groups. One group was comprehensively introduced into the system by the test administrator, the other group not. Both groups then had to perform the same tasks set: Logging in to the community, setting up a user profile, planing a hike including the invitation of friends to this hike, performing it supported by the smartphone application, and finally rating the route.

The evaluation of the ergonomics aimed to investigate whether the complexity of the system can be handled by the subjects of different ages and prior knowledge.

Figure 7 shows the time efficiency of four tasks of different difficulty that had to be performed by the subjects themselves autonomously. The graph shows the average time efficiency, defined by the absolute time spent in relation to the optimal path, of the subjects for performing a task, divided into the introduced groups. If a proband for example would have required 66 seconds to complete a task and could have done it with three "clicks", the efficiency is 66s / 3K = 22s per click.

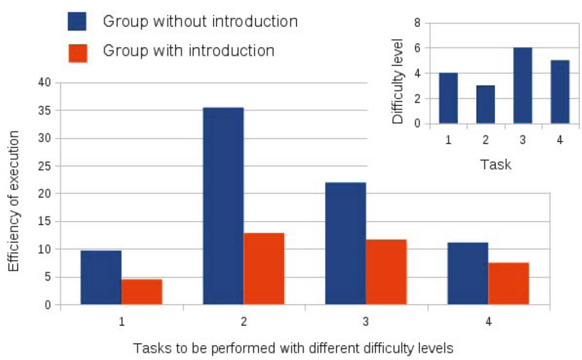

Fig. 7. Learning effect of the subjects

The first task was solved well by both groups, a clearly understandable entry into the community is given. While the non-introduced group needed still 35s for the second task, time decreased in contempt of increasing difficulty to 11s in the fourth task. The group with introduction recorded an efficiency increase of 13s to 7.5s. It is remarkable that both groups are approaching to the end. Theses insights lead to the conclusion that all participants are able to master the handling of the system and the assessment of the community is not adversely affected by the operability.

Following, the test subjects were asked to perform the planned hike with the aid of the smartphone application. Dealing with the sensors caused no difficulties for the test subjects. Only a lack of responses was noted, hence it was not clear whether the sensors were working properly, or whether problems existed. It was noticeable that a large number of subjects had difficulties with the Android-specific operation concept and so could not use some functions without assistance from the test administrator.

After the subjects completed the tasks set and then tested the system arbitrarily, a questionnaire investigates the subjective impressions regarding the operation and the motivation. The impressions about the individual questions were entered in a ranking on a scale of -2 to +2 (Strongly disagree to Strongly agree).

Figure 8 shows the evaluation with respect to the operation. The issues raised in the use of the Android-specific features were confirmed in the analysis, with the result that the intelligibility in this area has a negative value. Furthermore, it is here desired by the subjects to improve the routing, for example by inserting acoustic signals or a compass on the map. Overall, both areas were classified as legibly by the subjects, the objective of an age-appropriate user interface has been achieved. Problems with the intelligibility only affect certain functions - such as searching for other people - and can be easily corrected.

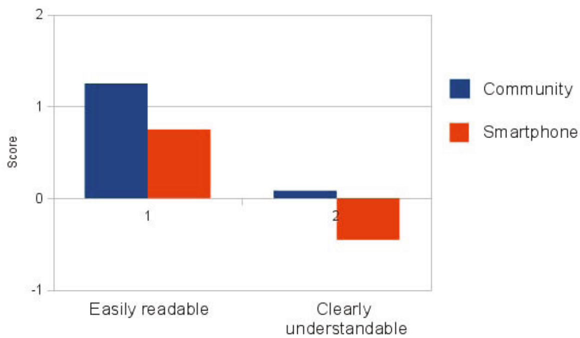

Fig. 8. Subjective impression of the handling

Regarding the motivation the evaluation results in a very positive rating of the RehaWeb system. On a scale of 1 to 4 different questions were rated on this topic. The result is shown in figure 9.

The first question fathomed whether the RehaWeb portal helps patients and interested parties to keep up motivation for continuous execution of the different forms of cardiac rehabilitation training. This question received with a rating of 3 a good, but also the lowest rating. It can be assumed that with respect to the growth of the community, concerning content and members, this value will increase. The smartphone supported hike joys most of the participants, the question whether they would recommend the system to other patients even reaches the maximum value. The desire for a subsequent 3-month test is also expressed by the majority.

7 Conclusion

The conducted user study clearly demonstrates that the main objective of increasing the motivation for patients of cardiac rehabilitation by the RehaWeb

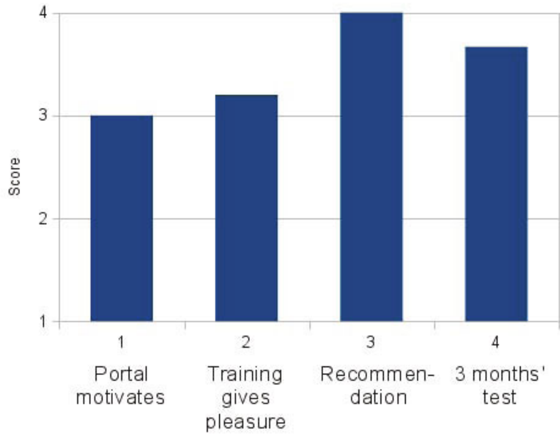

Fig. 9. Subjective impression of the motivation

system can be achieved. The likewise important medical requirements regarding a sensible supervision of training sessions and patients constitution over a specific period are met. Through the specially developed age-appropriate user interface no patients are excluded from participation, but the analysis of the study also reveals room for improvements at this point. From a technical point of view the selection of open standards ensures the sustainable maintenance. The ever-growing Android market also offers best opportunities to establish RehaWeb in the consumer sector.

The next step is the consolidation of the system, the addition of functions, revealed by the user study, and a clinical pilot program.

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3D Interaction in AAL Environments Based on Ontologies

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Abstract. The interaction between a technical system and the user is a main issue in information technology. In the field of Ambient Assisted Living (AAL) this is even more important due to the physical or mental restrictions of the users. Explicitly controlling a technically heterogeneous environment like a living area can be very complicated (e.g. using remote controls with complex interfaces) or even physically annoying (e.g. search remote controls or need to walk to a light switch). Thus, it is desirable to control the environment by simple pointing gestures or by using a centralized device. The base for this is a valid 3D representation of the environment including all required elements. In this paper, we present a new approach of an ontological representation of the real world and the dynamic service in-vocation according to this ontological 3D information. This concept is further described and validated by two application examples using a 3D GUI at a Tablet-PC and pointing gestures to control the AAL Space.

Keywords: AAL Platform, Semantic, Ontology, Interaction.

1 Introduction

One of the greatest challenges in the area of AAL is the controllability of open systems. Living areas, like a typical apartment with two rooms, kitchen, and bathroom, have to be prepared to move in or are subject of continuous changes, e.g. by adding new devices or furnitures or by changing needs or impairments of the user. At this point we quickly come to the conflict to harmonize the high complexity of that system with the ability of the user to control it. Controlling, in this case, means the explicit interaction with elements of the smart environment, e.g. to turn on/off the TV. Typical approaches include specialized controller devices like the remote control for a TV, or generic solutions based on graphical user interfaces on a PC. However, a more natural way of interaction would be preferred where 'natural' in this context means an intuitive usage of the user interface based on the fundamental abilities and preferences of the user him/herself. A good example for such a natural interaction are pointing gestures that can be used to control the devices of the environment (e.g. pointing at a lamp to light it up). The main requirement for these scenarios is a representation of the physical environment that is understandable by the system and that is able to store the actual location of the reactive element (the coordinates) as well as its semantic meaning. To fulfill the requirements of different and changing environments, this representation should be realized in a unified way and directly usable for the interaction with the system.

In this paper, we present a novel approach to model living areas based on ontologies and to directly use this representation to create different user interfaces and consequently unite the geometric description with its semantic meaning. We have created such an ontology for the AAL platform universAAL[1] and will describe its usage with two examples for different user interaction concepts.

2 Related Work

In this work, multiple different aspects have to be taken into account. As the main application domain is AAL, our work should be based on and integrated into an existing AAL platform that is able to work as an open system. The second aspect is about existing ontologies for modeling spacial data and their possibility for adoption. Furthermore, various interaction concepts need to be considered to refine the advantages of our approach.

2.1 Platform Projects

In the last few years, some national and EU projects have been funded in the area of AAL. The EU project universAAL, which started in February 2010, has as main objective the analysis of existing approaches to combine them in a unified reference architecture and to realize this with a reference implementation. The status of universAAL is quite advanced since several results (from architecture as well as implementation) from the input projects could be reused. The most important input project was found to be PERSONA, which has considerably advanced the support for context and user interaction [3][11] compared to Amigo [5]. Also, ontologies were not used in Amigo, but in PERSONA as a way to describe, perform a matchmaking, and invoke services for appropriate service requests. Other relevant projects include openAAL [13] which originated from the EU project SOPRANO [9]. This project also uses ontologies. For our work, we rely on the results from universAAL since it best fits our requirements on the architecture as well as the reference implementation.

2.2 Ontologies for Describing Physical Environments

A system dealing with human-environment interaction has to work based on a certain understanding (a model) of physical environments, especially locations and the physical things in them. The universAAL platform requires that such models are specified as ontologies. Our main requirements on the "physical environment" ontology has been: (1) high-precision in specifying places occupied

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

by physical things including indoor and outdoor locations as well as (2) support for transitions between different coordinate systems, e.g., from the pixel-based coordinates in pictures delivered by a webcam to the metric system appropriate for local calculations to the GPS coordinates used in global calculations. Both of these requirements necessitate that the ontology incorporates geometrical features that facilitate precise calculations. Flury et al showed that a location ontology supporting geometrical precision has to incorporate the concepts Shape, Coordinate System, and Transformation [4] but the provided ontology introduces only few related upper concepts; Baglioni et al do not include concepts related to indoors [1]; Chella et al include indoors but do not consider shapes and transformations [2]. A minimal ontology that satisfies our requirements is the one that we have developed in 2008 in the context of the PERSONA project [2]. We introduce this ontology in Section X.Y. However, in a recent publication, Hois uses the Industry Foundation Classes [3] and introduces a set of ontologies [4] in [7] that are based on a thorough analysis of related concepts. We plan to compare the two ontologies in the near future and migrate to the ones provided by Hois if possible.

2.3 Interaction in Living Areas

A theoretical approach for natural interaction with smart environments was already described in a previous work [8]. The basic idea is to select the modality (or a combination thereof) that best fits the preferences and impairments of the user to interact with the system. Existing approaches mostly use a graphical user interface, often realized as web interface, e.g. in the commercial solutions RWE Smart Home[5], HomeMatic[6] or ReCon[7] which have already found their way to the market. In the scientific community, more advanced approaches are available. For example, Stahl et al.[10] introduce the concept of “Synchronized Realities”, which use a bidirectional connection between a virtual and the physical world so that changes in one representation are reflected in real-time in the other one. Although this approach would be realizable in our concept, we focus on a generic approach independent from the modality, while Stahl et al. only use a graphical user interfaces.

3 Interaction Concept

This section is dedicated to the details of our approach. After giving a general overview of the whole system, the individual aspects are described.

[2] http://www.aal-persona.org/
[3] http://buildingsmart-tech.org/ifc/IFC2x4/rc3/html/index.htm
[4] http://www.informatik.uni-bremen.de/ joana/ontology/SpatialOntologies.html
[5] http://www.rwe-smarthome.de/
[6] http://www.homematic.com/
[7] http://www.recon-home.de/en/

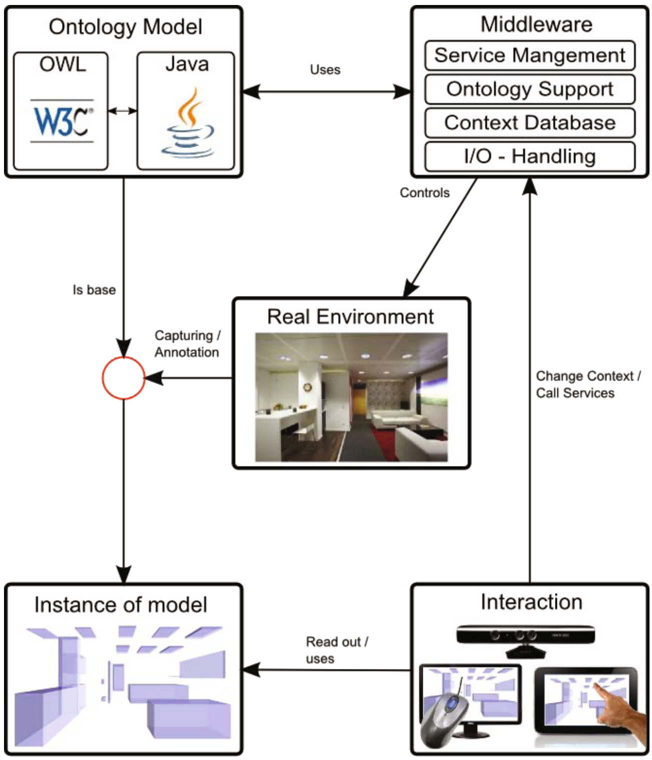


Fig. 1. Overview of the interaction concept

3.1 Overview

As shown in Fig. 1, our approach takes place in five different areas, where the physical realm constitutes the center which is both the starting point of an interaction as well as the end point in form of a device that is to be influenced. The remaining four areas are based on the used platform universAAL.

Before an interaction with the system can take place, we need a virtual representation of the physical environment. For that, an appropriate ontology for the description of living areas is combined with a method to capture the elements of the environment. The ontology created in this work is described in section 3.2 in more detail. Basically, in universAAL a representation of OWL[8] in Java is used. By capturing, we refer to the determination of position and dimension of all objects that may be of interest for the interaction and the description of elements of the smart space (e.g. furniture or devices like TV, but also walls and doors) as well as their properties and capabilities (e.g. the possibility to switch a TV on or off, but also properties like colors). More details on this will be discussed in section 3.3. By combining ontological description with the method to

[8] Web Ontology Language (OWL): `http://www.w3.org/TR/owl2-overview/`

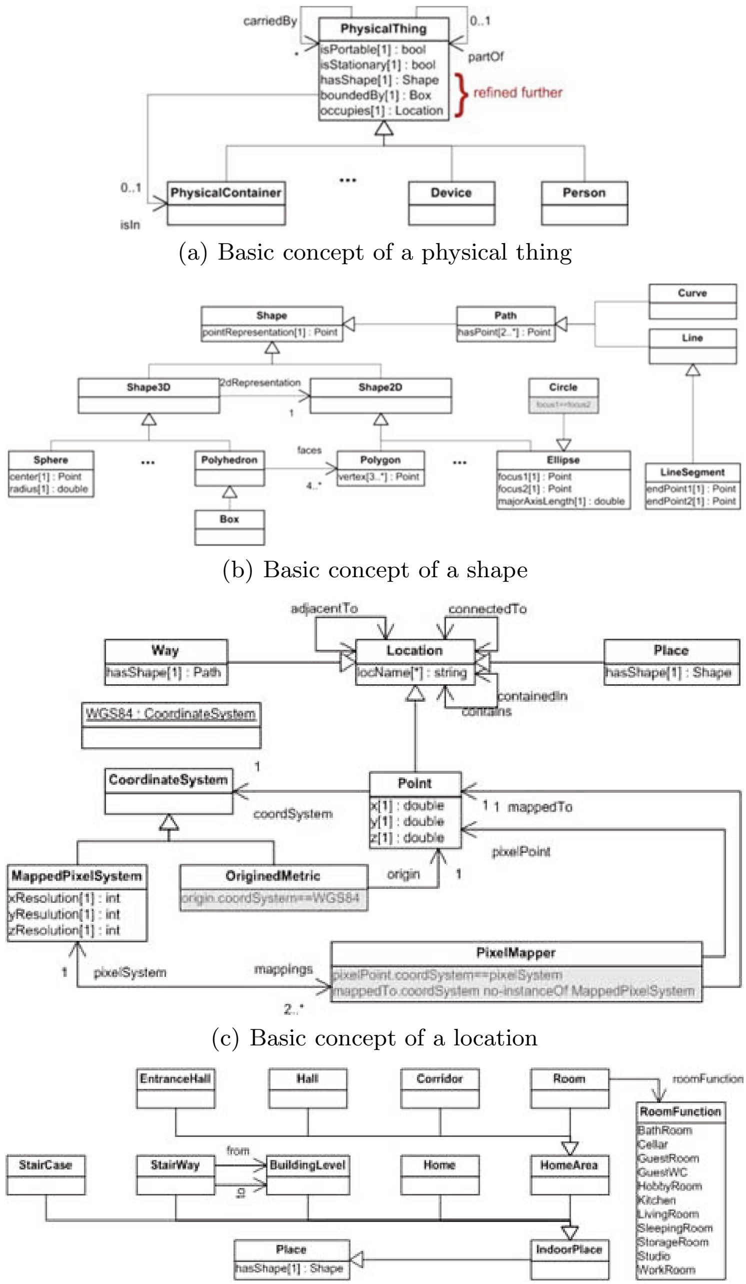
capture the objects of the environment we get a complete instance of the model with all required information to interact in a 3D environment. Devices that are attached to the AAL platform can now directly use the data of the instance of the model for interaction. More details on this can be found in section 3.5 and will be motivated by examples in sections 4.2 and 4.3. In section 3.4 some fundamental requirements for the AAL platform are defined so that this concept can be realized. Basically, these requirements cover the Management of ontologies and the controllability of devices attached to the system.

3.2 The Ontology for the Physical World

The ontology that we have developed for describing relevant parts of the physical world (presented in 2) solves the question about the geometrical precision by reflecting the three basic concepts Shape, Coordinate Systems, and Transformations, as recommended in [4]. The basic assumption is that both locations and physical things have shapes. Shapes can be specified with or without anchoring them to a physical location, e.g., an ellipse can be specified by two numbers for the distance between the foci and the length of the major axis or by specifying the positions of the two foci as points in a coordinate system together with the length of the major axis. Anchoring shapes to specific positions within a specific coordinate system occurs by specifying the position of some of its reference points. Points are specific occurrences of location; other kinds of locations are places and ways. Places can be indoor or outdoor. The coordinate systems in which points are defined can be mappable to each other. Such mappings provide for transformability of coordinate systems to each other. Based on the above, an ontological modeling of the different devices and their services has been provided. This is then used on top of a framework supporting context-awareness [3] in order to choose the service provider that best fits the current situation. All service requests made explicitly by the components participating in the system are also based on this ontological framework [12]. That is, the total coherence of the system is based on semantic interoperability between the system components while avoiding all kinds of syntactical dependencies beyond the shared ontologies.

3.3 Creating an Instance of the Model

As already mentioned, we need two things for the creation of the complete model: the ontology (described in the previous section) and the facts of the actual physical world. These facts are further divided in two main areas. First, the position and dimension of all objects of the living area (like furnitures or devices) that may be interesting for interaction have to be captured. The most simple way to do this is by manually determining this with a folding rule (this method was also applied for the examples in the next section). The coordinates are then made available in the system in an arbitrary affine space. The second aspect



(a) Basic concept of a physical thing

(b) Basic concept of a shape

(c) Basic concept of a location

(d) Basic concept of a place

Fig. 2. Ontology for the physical world like used for our concept

that has to be considered for the facts are the connection between the captured elements and their semantic meaning. This includes a description of their type (e.g. TC, sofa, thermometer) as well as their capabilities (e.g. switching a device on/of or providing measurements for the temperature). In our realization, all required information was made available based on the ontologies described in the previous section and their functionality was provided as services by the universAAL platform.

Please note, that capturing the semantic and physical data of a living area is not part of this work; some basic ideas for that will be described in section 5 on future work.

3.4 Requirements of the Platform

As discussed in section 2.1 we rely for our work on the platform universAAL because the reference implementation of this platform fulfills our requirements. However, since our concept does not necessarily require a specific platform, in the following some basic requirements are listed that an AAL platform has to fulfill:

1. Abstraction of hardware: devices in the living area must be controllable by a unified interface that is independent from the underlying low-level protocols.
2. Unique Identifier: The middleware must provide unique identifier (URI[9]) for each element.
3. Information management: the platform must provide information about the devices identified by a URI (i.e. their functionality and parameters) in a format that is understandable by the system as well as a human.
4. Ontological representation: it must be possible to realize the ontology described in section 3.2 and to access it at run-time.

The importance and meaning of these requirements are demonstrated by the examples described in sections 4.2 and 4.3. The concrete implementation in universAAL is further discussed in section 4.1.

3.5 Interaction

The semantic model derived in the previous sections can now be used for interaction with the devices in an AAL space. For that, the input device needs to provide a (normalized) directional vector v and the position vector p. For example, a camera based pointing gesture system could use the pointing direction of the user's arm and the position of the user as the vectors v and p, respectively. If a tablet PC with touchscreen is used, the directional vector could always be $v = (0, -1, 0)$ and the position vector p would be determined by the position of the interacting finger of the user (possibly scaled according to the scale of the map that is shown). The sections 4.2 and 4.3 will further discuss these two examples.

[9] Uniform Resource Identifier (RFC 3986) or Internationalized Resource Identifier (RFC 3987) can be used.

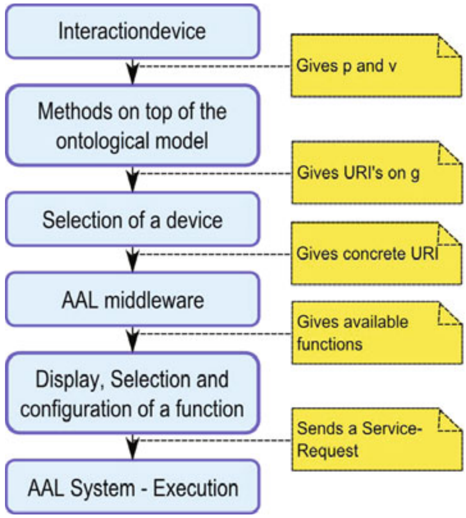


Fig. 3. Pipeline of the interaction process

Fig. 3 shows the overall process of an interaction with the system. With the two vectors v and p, a line $g : x = p + t * v; t \in R^2$ can be determined that can be evaluated in model space to determine all n objects $(m_1, ..., m_n)$ which may be relevant for the interaction together with their dimensions $V_i : i \in (1..n)$. Depending on the input device, a cone could also be used to account for increasing measurement errors with increasing distance.

If multiple objects were determined in this first step, a single device m_i has to be selected. For this selection process, different approaches can be used, e.g. the object that is closest to the user could be chosen. The selection could also be done by the user her/himself by providing her/him with a list of these objects (in a modality that best fits the users preferences and impairments). This list may be sorted, e.g. by distance or based on the frequency of usage so far. Additionally, semantic information may be incorporated like the neighborship of the objects or the context of the user.

The URI of the selected object m_i can be used by the platform to find out the set of functions together with input parameters that can be used to invoke that function, e.g. the functions *setPower(boolean)* or *setVolume(int)* for a TV. Again, from this set a selection has to be made, e.g. by taking into account the context of the user or by letting the user decide. After a last step to determine the input parameters, the appropriate method provided by the platform can be invoked and, if necessary, feedback about the outcome of this invocation can be presented to the user.

4 Implementation

After describing the general concept in the previous section, this section will demonstrate out concept with two examples. First, a short overview over the concrete usage of the platform universAAL is given. Then, we introduce the examples which are based on Microsoft's Kinect and a 3D GUI on a tablet PC. The focus for these demonstrators is not on the creation of user interfaces that are usable by end users, but on the possibilities of our approach to be used be different interaction methods. For that reason, a usability study with end users is not part of this work, but is future work.

4.1 Usage of the universAAL Platform

The current version of the universAAL reference implementation is written in Java and based on OSGi[10]. The platform as well as the ontological models are provided dynamically as bundles for Apache Felix[11]. universAAL uses its own realization of OWL; every semantic model is a set of Java classes and every ontological class (like the ones described in section 3.2) corresponds to an appropriate Java class. Every class of the ontology as well as every instance of these classes must have their own unique identifier in form of a URI. As an example, we want to model light sources and we assume that the basic concepts like *Device* and *Location* are already provided. Then we can define a common namespace which is used as a prefix for all elements in the living area the represent light sources, e.g.:

$$Namespace = "http://ont.universAAL.org/Lighting.owl\#"$$

All classes with this namespace form an OSGi bundle. The basic concept of a light source is then created as a subclass of the existing class *Device*; it has the URI

$$URI\_LightSource = Namespace + "LightSource"$$

LightSource and its properties like brightness (given as percent to the maximum brightness) are part of the Ontology Model shown in Fig. 1. At run-time, an instance of *LightSource* (e.g. *myLight0*) can be created that also must have its own URI:

$$URI\_Light0 = URI\_LightSource + "Light0"$$

This instance is part of the *Instance of model* as shown in Fig. 1. Since *LightSource* is a subclass of *Device* it inherits all properties of that class, including the *Location*, which contains the position of that device in the physical world, and a *Shape*, which contains the dimensions. A new property that *LightSource* does

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

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

not inherit is the brightness. This information is already enough to calculate the intersection between a *LightSource* and the line/cone we get from the input device (see section 3.5).

The remaining required information is the specification of the functionality of the device. For this, we can use the capabilities of semantic matchmaking of services provided by universAAL. Every service has to register its functionality in form of a *Service Profile* which basically describes the input and output parameter of that service based on the ontological model (the profile itself is also part of the ontology). For example, a service can be created that takes as input parameters the URI of a *LightSource* and an integer value for the brightness. If *URI_Light0* was selected as device m_i to be controlled by the device used for interaction with the user, the platform can query the appropriate service for light sources and invoke the appropriate function. Presenting the set of functions for a device and gathering the required input parameters is the responsibility of the calling application.

4.2 Interaction with Pointing Gestures

The first demonstrator uses Microsoft Kinect to recognize pointing gestures to select and control devices of the AAL space. Controlling, in this case, means to set a level of an object, e.g. to set the brightness of the light or the volume of TV or hi-fi system. As every object is an instance of one of the ontology classes, the Kinect with its position and orientation is also available in the location ontology. The service responsible for gesture recognition queries the information of this camera and waits for incoming skeleton data to perform the process of recognizing pointing gestures which are detected by analyzing the angle between the upper and lower arm. If this angle is beyond a certain threshold for a certain number of consecutive frames, the start of a pointing gesture is assumed. By taking the 3D point of the shoulder and the hand, a 3D ray relative to the enclosing room can be calculated. The location ontology, represented as Java classes, provide the possibility to compute all objects within a specific room that intersect with that ray or, to be more precise, with a cone generated from the ray, to count for measurement errors with increasing distance. Thus, the location ontology supports the developer on device selection by calculating all objects intersecting with the pointing direction of the user.

As soon as a device is selected, a graphical user interface is shown on the monitor next to the user (typically on the TV screen) to inform the user that he is going to control a certain device (see Fig. 4). The user then has to move his hand to a comfortable position which is marked as a zero point. From this point on it is possible to control the current level by moving the hand up or down as shown in Fig. 5. The interaction is stopped by moving the hand sideways to either cancel the operation (moving left) or acknowledge the current setting (moving right). The necessity of the step to move the hand to a comfortable position becomes clear when considering the type of interaction needed to set the level. When the user wants to control the ceiling lamp, he has to point directly upwards. If this point would be taken as the zero point, then it is not

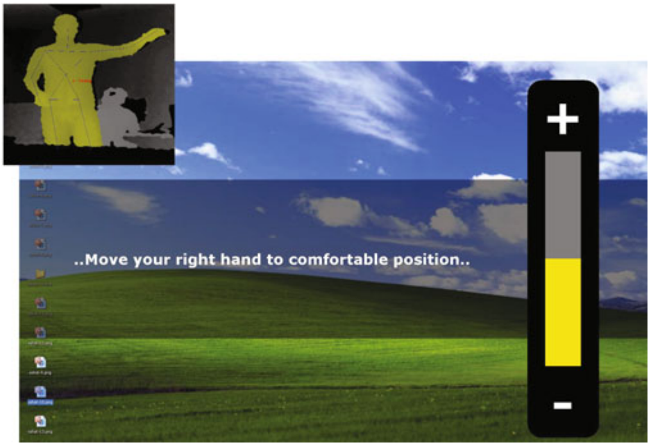


Fig. 4. Initializing interaction with pointing gestures using Kinect. On the top left the output of the Kinect is shown.

easily possible to increase the brightness of that light because the user can not move the hand upwards in that position.

4.3 Interaction with Graphical User Interfaces

Another possibility to use the concept described in this work is the use of a graphical user interface. To demonstrate this, a 3D visualization on an Android tablet PC was implemented which can visualize all facts of the ontology on instances of *PhysicalThing* (everything that has a position and a bounding box). Since visual parameters like textures are currently not part of the ontological model, the objects are shown as simple boxes. To make the visualization more realistic, and, thus, more intuitive to interact with, it provides the possibility to enhance the 3D model by some pre-defined models according to their type URI, so that e.g. light sources (identified by *URI_LightSource*) have a more visually appealing appearance than a simple bounding box. The output for our test environment is depicted in Fig. 6.

Please note, that universAAL is currently not available for Android. Hence, the realization uses a client/server solution to transfer the 3D model between an universAAL-aware PC and the Android client over TCP/IP. To exchange the necessary information, the client creates a 3D model in the XML based format *X3D*[12] which is enhanced with meta data. This way, the URI of the concrete element as well as the URI of the type of that element can be integrated in the 3D model and evaluated on client side. The calculation of the intersection between the line g and concrete objects to derive a list of relevant URI's is performed on the tablet itself. The click position on the touch screen is taken as position vector p and the viewing direction of the camera is taken as the directional vector v. If a

[12] Extensible 3D - `http://www.web3d.org/x3d`

Fig. 5. Controlling a device by moving the hand vertically to set a level, e.g. the volume of a TV

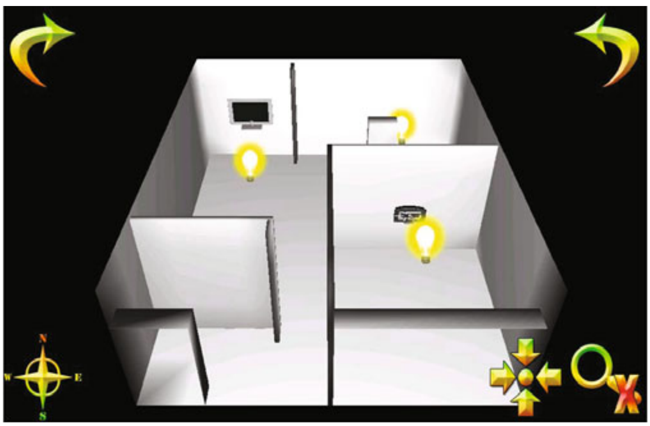


Fig. 6. Screenshot of the 3D GUI for Android based tablet PC

device is selected, the URI of that device is transferred back to the server which creates a list of all functionalities according to the registered service profiles. This list is then presented to the user as shown in Fig. 7.

The current version only supports boolean operations (e.g. turning a device on/off). Please note, that this is not a restriction of the concept, but of the concrete implementation. A porting of universAAL to Android has already been started, it is assumed that the client/server solution is then no longer needed.

5 Conclusion and Future Work

In addition to smaller adaptation and modifications to the concrete implementation, some important enhancements are possible to refine our interaction concept.

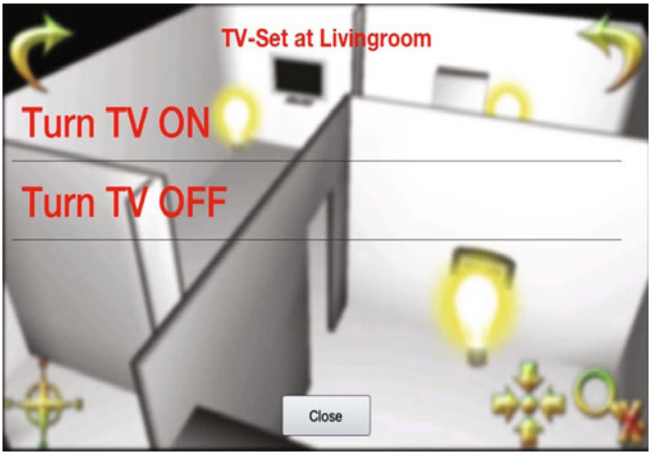


Fig. 7. Menu to select a functionality of a selected device

This especially applies to the creation of the instance of model as described in section 3.3. Considering the diversity of a continuously changing living area, it is hardly feasible to measure every change in the physical world by hand as was done for the two demonstrators. Furthermore, it is arguably impossible to think of all possible devices and functionalities that could be connected to the system to provide a model of them, especially when considering the usage by the end user. Thus, it is preferable to support at least semi-automatic methods for these aspects to allow for complex interactions in arbitrary environments. In the area of capturing the geometry of the environment (e.g. as scatter plot or triangle mesh) considerable progress has been achieved (e.g. by Gu et al. [6]), especially when taking into account the high availability of low-cost depth cameras like Microsoft's Kinect which is provided with an open API[13]. The approaches to automatically recognize objects in the physical world could be used as a basis for an ontological model. This step of annotating in a 3D space allows for interesting research opportunities, for example, to automatically identify objects of the living area (e.g. a TV) in a representation captured by a depth sensing camera. Additionally, it would be interesting to find out whether ontologies could be enhanced dynamically by the user instead of providing her/him with a predefined set of ontologies. However, the combination of automatically capturing the environment, the possibility to annotate the reconstructed objects and the interaction concept based on ontologies as described in this work seems to be a very promising foundation for a natural interaction between the user and the smart environment.

[13] http://research.microsoft.com/en-us/um/redmond/projects/kinectsdk/

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Part VII:
Training Systems

SmartSenior's Interactive Trainer - Development of an Interactive System for a Home-Based Fall-Prevention Training for Elderly People

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Abstract. In this article we picture the process of development for an interactive training system for the prevention of falls for older people in the project SmartSenior. Initially, we will depict the medical background of falls, which is the basis of the user-centered design of our device. Following a thoroughly evaluation of evidenced-based therapeutic strategies and a detailed requirement analysis, an interdisciplinary team consisting of physical therapists, medical practitioners and system engineers developed a technical architecture to enable older people to train their individual functional deficits via a home based telemedical infrastructure. Furthermore, we describe the sensor technology, feedback system used for motivation and correction of the trainee and the security model for the transmission of movement data to an assisting physical therapist.

1 Background

Falls are one of the most important factors in the development of loss of function and independence for older people. [1]. 30% of those over 65 years fall once per year [2], [3], 15% more often [2]. In a prospective study which examined the risk factors in a very old home-dwelling population of 85 years and older 49% many participants of the study population have fallen multiple times during an 11 month period [4]. The consequences are stern. Many falls result in – often trivialized – bruises and soft tissue damage as well as fractures of the femur, spine, humerus or distal radius. Falls are responsible for over 90% of all fractures of the femoral neck and 50% of all spinal fractures [1].

The demand for adequate preventive therapeutic strategies is obvious. Several recent systematical Reviews of the Cochrane Collaboration [5-7] could demonstrate the suitability of different therapeutic strategies like balance and functional training [5], [6], strengthening exercises or Tai Chi [5] in reducing the fall risk of older people. It also could be shown that multimodal training concepts – those which incorporated two or more strategies – were more effective than single-concept strategies alone [5]. Furthermore, those exercises should be performed continuously to avoid a drop back of the functional capacity and consequently a heightened fall risk of the elderly [6].

But especially this training continuity improved to be a problematic issue. Short-term improvements of functional abilities can be achieved with supervised training [8], in the long run, supervised training seems to be financially not feasible. Hence, the integration of home-based therapy is not only economically reasonable, it also seems to be more effective [8], [9]. Prerequisite for a successful home-based training program however is supervision through adequately trained personnel [10]. Telemedical technologies seem suitable for this supervision [11]. To show the suitability of this approach in the SmartSenior-project we aim to develop an interactive program for a telemedically supervised training for fall prevention.

2 Architecture of the System

The so called "Interactive Trainer" consists of a computer and different sensor systems, which enable the user to practice exercises tailored to the needs of older people at risk of falling. Providing individual therapeutic feedback about the quality of their exercises is one of the main features. Additionally, the Interactive Trainer enables the patient to get into contact with a therapist via A/V-communication, either as part of a scheduled meeting or to solve arising problems. The sensors are ambient (camera and microphone) as well as inertial (a 3D-accelerometric system build into a belt). All exercises by the user are mapped by a combination of both sensor types. The mapped movements are analyzed in real-time and displayed on either a computer monitor or a TV screen.

To simulate a "real" one to one therapy as good as possible, we developed an intuitive dialog system to lead the user through the program and to give him correcting and motivating feedback during his exercises.

The combination of wireless transmission of the sensor data and built in ambient sensors has the advantage that the patient can move without any obstacles and risk to fall in fact of cables lying between him and the training PC. The feedback is given visually on the TV-Screen or PC monitor and accoustically using the loudspeakers of the TV. For connection with the therapist the training PC needs an ordinary internet access.

Before starting the training the senior gets the individual and actualized training plan onto his PC via a request of the online database in the Charité. After the training session the excerzise data, e.g. training results, are transmitted to the electronic health record in the safe and secure server backend of the telemedical center of the Charité. The security is guaranteed by the implementation of a Public-Key-Infrastructure and encryption of the data to be transmitted. Using a therapy editor the therapist can configure an individual training plan for the senior.

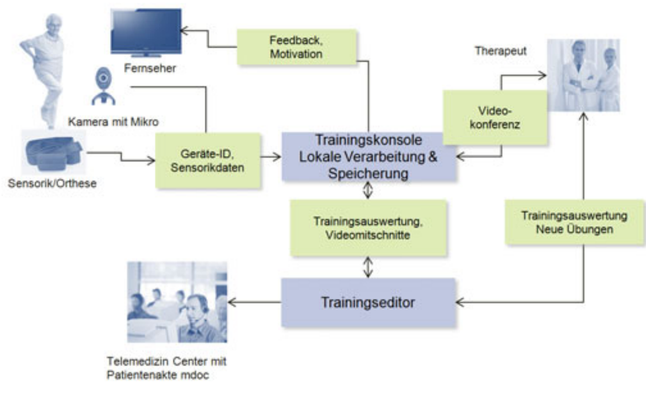

Fig. 1. Overview "SmartSenior Interactive training system"

3 Sensors

The exercises of the patients are detected by a combination of sensors. They consist of the „Kinect" camera (Microsoft Systems) and a newly developed body near sensor system of the Humotion GmbH. The Kinect was developed by PrimeSense and Microsoft as a *Natural User Interface* (NUI).[1] It offers the detection of a 3-dimensional skeleton in realtime. The 3D-detection is done by triangulation. An integrated projector emits IR patterns invisible for the human eye. An IR-camera captures all relevant points of the user during his movements. Due to the stationary position of both - the IR projector and the camera - this data can be used to generate a 3-dimensional cloud of the points. The open software library OpenNI and NITE[2] is used to transform this cloud into a 3D-skeleton. This skeleton has 15 parts: Head, Neck, Shoulders, Elbows, Hands, Torso, Hips, Knees and Feet)[12].

The Humotion sensor system provides additional data and consists of several different sensors such as a 3D accelerometric sensor, including the constant acceleration of gravity (1g=9,81 m/s²). This enables the system to detect the vertical axis in space even when the user is not moving. The horizontal axis is measured through a 3D magnetic field sensor. A 3D gyroscopic sensor measures rotational speed as a deviation from 0 rad/sec in one or more axes. By integrating rotational speed data with starting values and position data the gyroscope provides solid angles during all movements. Deviations from measurements are assessed during movement stops and

[1] NUI – Natural User Interface.
[2] `http://www.openni.org/`

exact positions are recalculated by comparing the measured in relation to the exact positions. Resulting data show three solid angles in space in reference to rotation data of the system described as eular angles or as mathematically more exact description of the quaternions. The motion data is transmitted to the training PC using the wireless communication standard IEEE802.15.4 that enables data transmission by 6LoWPAN. As transmission protocol UDP/IPv6 will be used.

4 Evaluation of Different Therapy Concepts and Description of Prototypical Fall Prevention Exercises

To identify therapeutic concepts fitting into the idea of the Interactive Trainer, we conducted a systematic review in PubMed. We used 27 MeSH and 28 free search terms, combined into 516 search phrases. After applying limitations as age (50+), study design (RCT) and available abstracts we found 1256 articles, which were consequently examined by two independent researchers. We finally were able to break down all available and identified studies into 12 therapeutic concepts and evaluated their evidence and feasibility for use in the Interactive Trainer.

This analysis showed good evidence and feasibility for three different therapeutic concepts. For this reason, we integrated exercises for balance and strength with high repetition. Our first exercises were defined as:

1. Walking while sitting
2. Weight shifting while sitting
3. Weight shifting to both sides while standing
4. Weight shifting to the front and rear while standing
5. One-leg-standing
6. Sit-to-stand from a chair

Below we want to describe the one-leg-standing as an exemplary exercise for balance improvement.

In this exercise the patient has to stand on one leg while keeping his Body upright and the whole body as stabile as possible. The exercise starts in upright standing with spread arms for balance assistance. Now the patient shifts his weight to one side while raising the non-supporting leg until reaching a 90° angle in hip and knee. The patient keeps this position for a defined time (1 to 20 seconds) before lowering his leg, changing the side of the weight shift and raising the other leg. Body and arms should be kept stabile during the whole movement. This way, a constant change between supporting and non-supporting leg with increased balance and strength requirements is generated. Qualitative assessment of this exercise includes body stability through all movements, height of moving the non-supporting leg and involuntary or compensation motions of body, arms or the non-supporting leg.

This exercise description was the basis for specifying necessary components for the detection, analysis and evaluation of all motions during exercise.

5 Detection, Analysis and Evaluation of Exercises

To measure the correct performance of exercises a redundant data integration method of optical and inertial sensors was chosen. This is done in order to get the most precise data for the analysis and evaluation of exercises.

Using the Kinect only a relatively coarse skeleton of the user will be detected. For example the user's spine is represented by only a single point. Such representation is insufficient to detect deviations from the longitudinal body axis timely. According to the therapists' requirements even the smallest deviations between desired and actual value that imply a possible fall risk, have to be detected.

Therefore the Kinect data is merged with the inertial sensor data. The inertial sensor has to be calibrated because the measured orientation depends on the magnetic field of Earth. This is done with a transformation of the global coordinate system (magnetic field of Earth) to the local coordinate system (user's spine). For this calibration task the Kinect can be utilized, because it provides confidence values during the skeleton detection. If the measured confidence value of the Kinect-detected spine orientation[3] exceeds a predefined threshold the sensor orientation will be set to this orientation. After this the data of the calibrated inertial sensor can be used on its own. Also the mean between inertial sensor data and Kinect data can be calculated or the Kinect data can be used for plausibility tests.

To measure the quantity and quality of the performed exercises it is analyzed and evaluated. Besides a quality statement at the end of each exercise also a live feedback is given. This live feedback subsumes the verification of exercise-specific body poses, the desired amplitude of movements and the execution speed. As the evaluation basis serves a reference user-exercise that has been captured under the control of the therapist (so called teach-in functionality) as well as predefined exercise-specific evaluation criteria. The evaluation results will be provided to the other modules of the interactive training system (Graphical User Interface, dialog system, etc.).

5.1 Workflow of the Analysis and Rating Component by Using the Example of the One-Leg-Standing

First of all, the motion data captured by the kinect sensor has to be normalized to ensure that the individual location of the user in front of the sensor does not influence the posing results. After that the initial posture which the user has to get himself into is detected. Therefore it's necessary to compare the actual motion frame with the first motion frame of the reference model.[4] If the actual posture is equal to the required initial posture, the analysis and rating component will inform the post processing modules like the GUI (graphical user interface) and the dialog system. As long as the challenged posture is incorrect visually the deviations are shown per part of the body using a straight forward metaphor like traffic light signaling. Green color is the rating for a good motion performance and red is a signal for incorrect motion.

[3] Vector between hip, torso and shoulders.
[4] Every exercise reference model starts with the defined initial pose.

To inform the user about the quality of his/her current movements while practicing, the system has to continually generate a real-time rating. In case of the "one-leg standing" exercise, the upper body as well as the right and left upper leg and both the lower legs are defined as regions of interest. This selection provides the basis for the posture rating. Furthermore the system checks and rates the stability of the upper body, the arm symmetry and balance, the pace and also some time restrictions. These results are sent to the GUI and dialog components again. The used protocol sends messages like "You are too fast", "Please pay attention to your body posture", "Keep your arms constant", etc. An especially adapted segmentation algorithm detects and counts the repetitions and stops the training set when all required repetitions are completed.

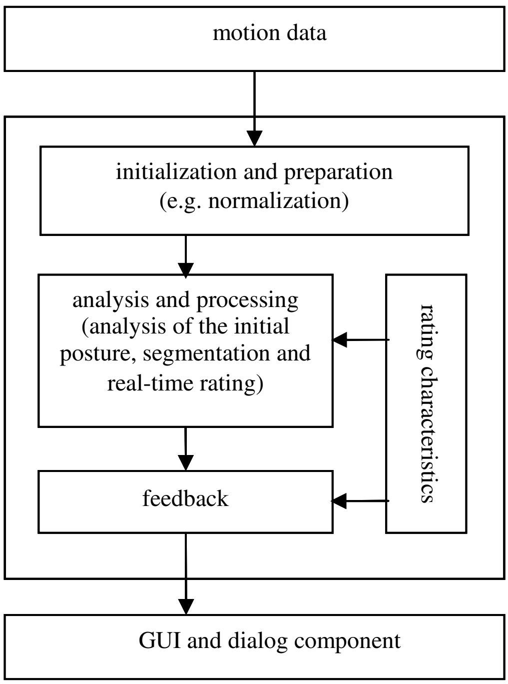

Fig. 2. Motion analysis and rating component providing feedback to GUI and dialog system

6 Feedback to Users

To assist and motivate the user while practicing, a multi-modal system was developed. Therefore the dialog system "ScenceMarker" [5] was implemented which is controlled by the dialog manager. The dialog manager has to pass incoming signals to the

[5] Java Toolkit entwickelt von Patrick Gebhard.

actual dialog scene. The dialog scene generates an appropriate feedback. The implemented dialog system is able to load and trigger several dialog scenes simultaneously on runtime. The created feedback is passed to the interaction manager which assigns the feedback data to the requested output modality. It is possible to take different ways (visual, tactile, verbal) to present the feedback to the user. To inform the user about the quality of his or her current movements while practicing, the system has to continually generate a real-time feedback. For this purpose, the main concept follows a straight forward traffic light metaphor (well done, carful and badly done).

For handling the events an interaction manager has been developed that processes synchronous and asynchronous events and dispatches them other components of the system. Synchronous events are needed for usual dialog flow. Therefore the system generates an interaction state. The user can react using an input device like speech or remote control. The events and possible user inputs are defined by the state of the program flow. Asynchronous events are handled as non expected system inputs by the user. These non expected system inputs are used to handle posture failures or incorrect body movements during the execution of the exercizes. They are based on the protocol provided by the motion analysis and rating component. According to the failure a visual or acoustic advice is given to the user. Critical or again incorrect detected motions lead to a break or pause of the exercize program.

In order to communicate with the senior in an almost natural way a synthesized voice output (TTS – Text to Speech) and a speech recognizer (ASR – Automatic Speech Recognition) have been integrated. In future further asynchronous messages like deviations from normal vital data (e.g. heart frequency, pulse) can be implemented as well as an interface for providing tactile feedback on the body near sensors of the seniors using the home-based fall-prevention training system.

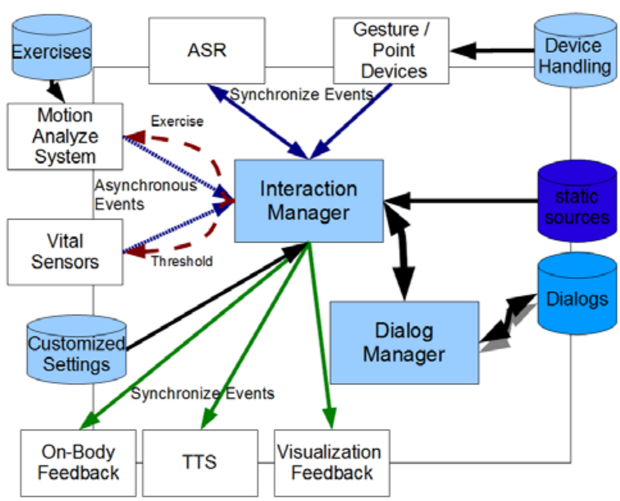

Fig. 3. Interaction manager handling feedback events

7 Secure Data Transmission

The treatment plans for the individual patients are managed with the aid of the online database mdoc[6], using an installation at the TMCC (Telemedicine Center Charité). Before starting the actual training, the training console retrieves the updated plans, and at the end the training results are transmitted. In both cases, for the communication web services are employed.

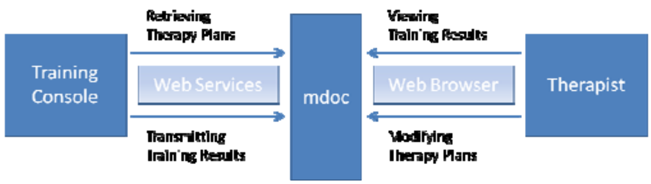

Fig. 4. Communication with mdoc

The therapist is able to view the results via a web browser and when indicated may also alter the therapy plans.

To support communication between the training console and mdoc a local MySQL database is used. At first, the retrieved therapy plan together with a related hash value is stored in the local data base on the Training Console. Later, this hash value serves to identify modified plans. Further transmissions of the whole data set are only necessary if modifications had been carried out. Likewise, the results of the exercises are initially stored in the local MySQL database and later are transmitted to the TMCC by using web services. In this, the database schema has been implemented as shown in Fig. 5:

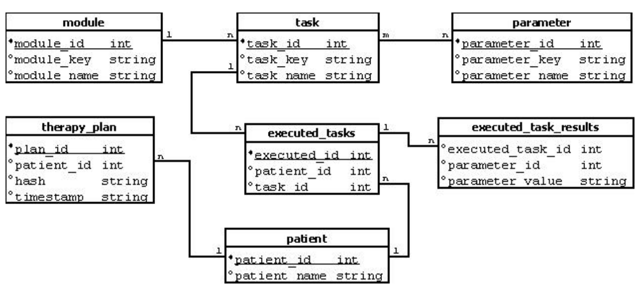

Fig. 5. Schema of the local MySQL database

All in all there are 11 exercises divided into two groups “stroke” and “fall”, and for each exercise there are a number of parameters. The exercise results to be stored

[6] http://www.tembit.de/1/healthcare/mdoc/

include measured values for these parameters as well as a timestamp, the duration of the exercise and the degree of fulfillment (parameter_value).

To guarantee privacy, data integrity, and data security as demanded for personal data by the Data Protection Act, each component has to verify the identity of its counterpart. Prior to transmission the data has to be encrypted, and the completeness of the transmitted data has to be ensured. For this purpose the project SmartSenior has established its own public key infrastructure[7], all participating servers and clients, therefore also the training console, are equipped with corresponding signed certificates, and for the communication the protocol HTTPS[8] is employed.

8 Design of Graphical User Interface

The therapeutic success of the Interactive Trainer is fundamentally dependent on the acceptance of the system and the intensity of use of the intended users. Essential for the acceptance are the design of the user interface and integration of motivational elements into the exercize program. The better the expectations of the target group are mapped and incorporated into the exercise flow, the easier the skepticism about a new and unfamiliar system ("entry barriers") can be overcome.

Therefore, the Interactive Trainer for fall prevention will utilize

- Avatar design (3D visualization of the movement of the subject)
- Virtual therapist (3D visualization of the reference motion / male and female virtual therapist)
- Motivational feedback systems (goal accomplishments, color design of the motion sequences, easily understandable, visual cues during exercise performance [traffic light system], audiovisual commendations, rankings, display of progress)
- Corrective feedback systems (understandable, visual cues during exercise performance [traffic light system], termination signals in self-endangerment)
- Tutorials (Teach In, presentations for practice in a second window during exercise execution)
- Target group-specific environments (Use of target-group-specific experience realms in the visualization of "game environments" such as "domestic environment" and "park", selection of exercises and games from activities of everyday life)

The gentle and individually scalable design of the exercize sequences is also essential. As a first step, the therapist and the user create a profile during the "teach-in" (choice avatar design, the exercises and respective scenery). Then the therapist defines an individual practice schedule (level of difficulty) using the therapy editor, which will be used by the therapists to tailor the exercizes. Subsequently, the user will start the Interactive Trainer independently from a "home environment" and will be "taken by the hand" and motivated by the virtual Coach. After a welcoming and inquiry of the user's state of health they will be able to navigate the exercises and

[7] http://en.wikipedia.org/wiki/Public_key_infrastructure
[8] http://en.wikipedia.org/wiki/Secure_Shell

games autonomously through a selection menu. The therapist specifies the scope within the treatment via editor by individually adjusting the parameters to the needs of the user. The exercises chosen for the user are based on therapeutically sensible motion sequences that have to be completed in a specific manner. As a special "reward" the user can "unlock" the corresponding game. This occurs when the user has successfully completed the exercise according to the therapist's guidelines regarding the expected quality as well as frequency and the therapist in turn has unlocked the game with the therapy editor. The therapeutic results of the exercises are remote supervised by the therapist, especially in terms of continuous performance, accuracy of the motion sequences and the progress of therapy. The therapist will be able to step in and adjust the therapy plan and its exercising activities any time using the therapy editor.

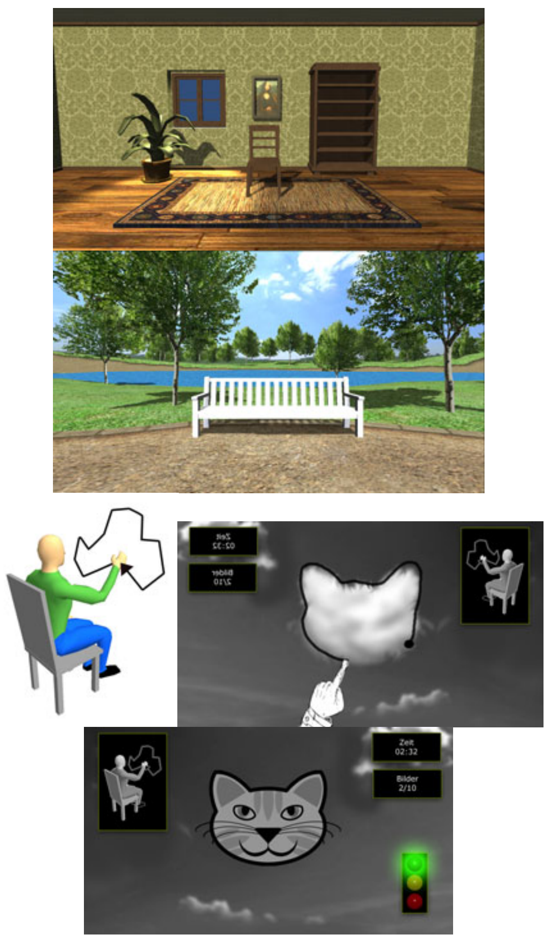

Fig. 6. Visualization of the graphical user interface

9 Conclusion and Further Work

In this paper we described the approach and the status of implementation of the interactive system for home-based fall-prevention training. While developing this system a user centered design methodology has been chosen in order to align the whole system to the requirements of the end users (seniors and therapists) and to introduce it as smoothly as possible into the processes of daily working and living. A leading issue was to come to the most evident exercizes from a therapeutical point of view therefore existing therapies have been evaluated and compiled to a new exercize program. The acceptance of the system is based on the individual tailoring of the exercizes and a minimum set of sensors dependent on the medical indication and requirements of therapeutic motion analysis.

The goal of the project is to integrate the system into the daily working process of therapists and to provide the needed features to "stay connected" with the seniors and patients. For this reason the trainings results will be documented in an electronic health record (mdoc). Using the therapy editor the therapist has the opportunity to plan and align further steps in the therapy process and he also can contact the senior using a videocommunication solution. Last implementation issues are the optimization of the feeback mechanisms according to the needs of the users we will derive from tests with seniors at the Charité. Data relevant for evaluating the acceptance and the costs of such a telemedical remote supervision service for home-based fall-prevention training will be assessed in a field test in Potsdamer apartments in spring 2012.

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Serious Gaming: Enhancing the Quality of Life among the Elderly through Play with the Multimedia Platform SilverGame

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Abstract. The objective of the SilverGame project is to develop a multimedia platform tailored specifically to the needs of the elderly by connecting play-based applications with web-based information and communication services to encourage mental and physical well-being as well as social interaction among the elderly. The project aims to offer users the possibility to enjoy within their homes, leisure activities such as singing, exercise and driving either alone or jointly with other users. They will also be able to access or exchange information using integrated online channels. A prototype multimedia platform and three serious games which can be played using the TV set are being developed by the project partners. The application is operated using an intuitive touch screen interface on a handy tablet computer designed specifically for the elderly target group. The multimedia platform is intended to be offered as a complete system including easy-to-install and easy-to-use hardware. The applications and the services will be available to buy on a modular basis permitting further upgrading at any time.

1 Concept: Objectives and Approaches

SilverGame pursues a clear objective: The multimedia platform is designed to improve the lives of elderly and isolated people. To achieve this aim, SilverGame has a different focus to most AAL applications which concentrate on aspects such as health or safety. SilverGame is first and foremost about “having fun”. The home entertainment platform is designed with the aim of enhancing enjoyment of life by offering interactive play-based multimedia applications which precisely target the social needs of the elderly population.

What exactly are the needs of the elderly population? What properties do the platform and the games need to offer in order to spread happiness among the elderly? These were the questions addressed by the project partners in their pre-project research. Their answers set out the direction for the development of SilverGame:

1.1 Community: Ways Out of Isolation

As they come to the end of their working lives, the elderly face the challenges of a whole new phase of life, which we usually call retirement. This name conveys the wrong impression. “On average, the older generation today reaches retirement in better health, with better qualifications and better financial security than the generations before”. [1]

What this means in practice is that in the 21st century, the 60+ phase of life is not only longer, but also plays a more significant role than ever before. However, studies show that elderly people are often unable to fully utilize the possibilities available to them because they live in social isolation. Around one quarter of 70 to 85-year-olds stay at home the whole day, with the exception of brief excursions to the shops or on walks. Even among 55 to 69-year olds, the proportion of “stay-at-homes” is as high as 14 per cent. [2]. Many fail to utilize their long-awaited freedom and flexibility after retiring.

This is where SilverGame comes in. The platform is designed to offer not only games to help the elderly pass the time at home, but rather to introduce a stimulus for forging contacts with others: Initially in a world delivered through the use of media, and then increasingly in the real world. To achieve these aims, three requirements have to be met:

- The games must offer leisure activities which are understood by the older generation in order to create a basis for joint activity.
- The games must have easy-to-operate interaction functions and must allow the leisure activity to be experienced jointly as a matter of course by the players.
- The games have to provide a channel into the real world. Current information relating to all aspects of the leisure activity, such as names and addresses, must be integrated into the fabric of the game.

The SilverGame concept addresses these aspects. The platform is designed to link the game-based applications with web-based information and communication services.

- Using typical community features and an integrated audio/video conferencing system, users can find friends and contacts through play and take part in community life.

- The tele-presence of friends and family members during the gaming process offers users the opportunity to share in emotional reactions directly and to exchange their own experiences live on screen.
- Supplementary information is provided to encourage real life encounters, for instance by motivating elderly participants to attend an event being held close by.

1.2 Serious Games with Added Value

As was explained at the outset, recent decades have seen not only a significant increase in life expectancy, but also an increasing need to remain active in old age. Older people want to remain mentally alert and physically fit to allow them to enjoy their retirement. This is a need that can be addressed through play: with serious games.

Serious games are digital games which communicate information, knowledge and skills through play, making them the ideal way for the elderly to stay fit and alert. They are fun, help train physical and/or cognitive skills, are conveniently available at home at any time and cost only a relatively small amount of money. Considering these benefits, their popularity among the elderly comes as no surprise. A survey carried out by Feierabend.de, one of the biggest social networks for the elderly, showed that mind and learning games as well as games of skill are right at the top of the popularity scale [3].

The problem is that the gaming technologies and titles available on the market are predominantly aimed at the needs and skill sets of younger users. They are frequently very complex and are beyond the capabilities of the 60+ generation. In terms of their content, they also have little appeal for older people; they fail to address the experiences or the interests of the older target group [4]. SilverGame aims to close this gap. Already in its prototype form, the open platform will feature three serious games which consistently address the needs of the 60+ generation and are designed to provide a model for additional target group-specific games in the future:

1. **Singing Club:**

Users have the opportunity to sing either alone in a karaoke-style mode or communally in the choir mode, and also to take part in live events. The results can be recorded and published.

2. **Dance and fitness Training:**

Users can select from a range of different dance and exercise programs, and follow demonstrations by a personal trainer. Participants receive sensor-supported feedback of their progress.

3. **Driving Simulator**:

Users can drive using this application either alone or jointly with another user, selecting between different scenic back-grounds. If desired, they can access sensor-supported feedback.

1.3 Music and Movement: Positive Repercussions for Body and Mind

The individual serious games devised by the SilverGame project are also aimed at addressing the social challenges thrown up by today's demographic transformation. The "Singing Club" and "Dance and Fitness Training" modules offer the elderly a common form of activity to encourage greater and more enjoyable movement – with the additional effect of improving physical health.

The importance of the interaction between music and movement has been proven by a study on the application of eurhythmic movement programs. One of its conclusions is that eurhythmics can stabilize the gait of senior citizens and reduce the risk of a fall [5].

Music and movement also play an influencing role in the early stages of dementia. A study performed by the Central Mannheim Institute of Mental Health established the influence of singing on the ability to remember, and described the positive effects of singing familiar folk songs [6]. After a medium-term time period of 15 weeks, an improvement was recorded in the cognitive and communicative abilities of all those participating in the study. Apart from these aspects, the combination of singing and movement strengthens the respiratory muscles and results in a significant improvement in breathing and consequently in the oxygen supply.

1.4 Driving Simulator: Greater Mobility and Safety

The driving simulator game provides an example of how the spectrum of the SilverGame platform can be consistently adjusted to keep pace with changing trends and the specific needs of older users. The number of car drivers has increased over the past three decades in every age group, and in the elderly age group particularly among women [7]. The proportion of drivers over 65 is forecast to rise significantly over the next three decades [8].

Most senior citizens enjoy driving. Alongside the fun aspect, driving is pivotal to maintaining mobility into old age, and so keeping up social contacts to relatives and friends. Every attempt is made to counteract health restrictions which could impair capacity for driving (glasses, hearing aids, automatic transmission, parking aids etc.). Despite this, older drivers tend to feel less and less confident on the roads with increasing age. Older men and women alike find navigating their way through traffic in unfamiliar cities daunting [9].

It is here that the driving simulator game comes into its own. Older road users find this a motivating aid which allows them to repeatedly practice driving situations, giving them confidence to deal with actual situations on the road. The gaming and interactive approach turns the process of improving driving and reactive skills into an enjoyable pastime. Simulated driving together is an enjoyable experience and can also help to address gender-specific aspects of ageing. Users can then finally practice and test their knowledge of (current) traffic regulations by completing an exciting quiz.

1.5 Simple Operation: Spotlight on the User

As most elderly people do not yet feel at home around computers or games consoles, they tend to mainly use simple games that they already know [10]. The highly popular games console “Wii” from the Japanese producer Nintendo is not aimed at the elderly target group. Although it offers games aimed at exercising mental and motor skills, in terms of their usability and prescribed movements, the games are not designed as safe and controlled applications for senior citizens. This also applies to operation of the platform.

Studies undertaken among the elderly have shown that they find the user prompting and operation of the “Wii” games console too complicated.

Studies carried out in this area also clearly highlighted a need for more research and development. The time has come to actively address the 60+ target group and work with this group to develop platforms and games they find easy to understand and operate.

To address this need, the SilverGame project advocates a user-centred development process. Right from the concept-finding phase, the needs of the 60+ target group were evaluated by means of surveys and focus groups. The results of this initial evaluation phase and their significance in setting out the requirements for project implementation are outlined in the following.

2 Evaluation: End User Requirements

Target group orientation is pivotal to the successful development of a multimedia and communication platform for the elderly. The devices have to be simple to operate, the user interfaces have be adjusted to the cognitive needs and skills of the 60+ target group.

The Lübben Rehabilitation Centre plays a supporting role for the complete SilverGame project in the form of user-oriented evaluation of the requirements, needs and preferences of potential end clients. Expert consultations with medical specialists (doctors, psychologists, sports therapists and physiotherapists) and driving safety instructors of the German Automobile Association ADAC are held to ensure that the platform design takes sufficient account of age-specific factors.

The Golden-Oldies charity in the UK engages hundreds of elderly people in professionally organised singing and exercise sessions. It is an invaluable partner in the Silvergame project.

During an initial evaluation phase, a questionnaire was developed which was used to determine the needs and preferences of the target group. 193 people were surveyed from a total of four European countries (Finland, the UK, Austria and Germany) using this questionnaire, which produced first indications for the possible technical implementation of the project.

The average age of those asked was 67.5 years, with significantly more women (62.2%) than men (37.8%). Around half of those asked already had an internet connection, a further 20 per cent expressed interest in using the internet at home in the future.

Further research included study of available literature on subject areas such as movement and health, singing and health, and cognitive capability in the elderly, and a set of conclusions was drawn up.

The results of this survey are described in the following chapters.

2.1 Platform and Games Controllers

Those participating in the first evaluation phase believed that the SilverGame platform and applications should be operated using a TV remote control; Almost 90% of those questioned indicated that this would be their preferred method. This is due to the fact that those asked are familiar with their existing remote control, but not familiar with touch screens. However, around 40% of those asked were very interested in the idea of operation using a touch screen, and consequently a decision was taken to use this system for the project. The benefits of using a touch screen are the scope for designing the look of the (virtual) operating elements. Buttons, fonts and other elements required to control the functions can be modified to suit the age group, which would be impossible using a conventional TV remote.

2.2 Serious Gaming Modules

Overall, the three suggested modules – driving simulator, sing for life and dance and exercise – met with a lively degree of interest. Around 50% of those asked in each case could imagine buying the system, as it would give them the opportunity to take part in this type of leisure activity despite ever increasing mobility restrictions.

It was noticeable that the elderly people asked were interested not just in the playing aspect but primarily in the idea of practising, exercising and acquiring a skill.

They requested games which would offer them added value, such as the driving simulator to improve their driving skills. This is a major challenge in the development of the driving module, as research in the relevant literature and interviews with experts from the ADAC indicate the limits involved here. Cognitive skills can be practised and improved by playing. However, transferring this to actual driving capability on the road is only possible with the highly realistic and therefore extremely complex simulation of traffic situations.

With all three modules, the users expressed a desire for feedback systems which would permit a certain response to the user input as well as traceability and a check of exercise results, but with a minor reservation for the singing module, where greater importance was attached to enjoyment of virtual choir singing than to any evaluation of individual performance. For all three modules, those surveyed also expressed that they would prefer to be given a choice of different levels of difficulty.

Following an analysis of the questionnaires and expert interviews, a number of requirements emerged which would have to be taken into consideration in development of the modules.

2.2.1 Driving Simulator

A number of key points had to be taken into account in the technical design of the driving simulator. Anticipated benefits of training were expected in a number of areas, including: lane keeping, right of way decisions, distance keeping, economical driving and traffic regulations. The selection of possible practice scenarios would revolve around driving ability, i.e. existing performance level. The problem areas specific to different age groups would also have to be taken into consideration; 60-65 year-olds have different requirements to 75-80 year-olds.

2.2.2 Singing Club

For the singing module, the survey indicated that users would welcome warm-up exercises to be offered to help prepare for achieving a certain level of performance. The feedback system should allow a comparison between the real melody and what is actually sung. There should also be facility for choosing different levels of difficulty, which would allow users to determine their own performance level. Where users choose communal singing together with other module users, this feedback function and assessment of vocal performance can be deactivated.

2.2.3 Dancing and Fitness Module

For the dancing and fitness module, it should also be possible to differentiate between performance levels, especially in view of the varying levels of health and fitness among 60 year-olds. Gymnastic exercises and stretching routines should be designed to be performed either standing or sitting.

For the younger end of the spectrum, the emphasis can be on endurance, mobility and coordination, while for older users (80 plus) the concept of fall prevention should be additionally incorporated and less emphasis placed on endurance. The exercises should also be designed so that they ensure practice of everyday situations (e.g. going up stairs).

3 Implementation: Platform and Multimedia Modules

3.1 Man-Machine Interfaces: Intuitive User Interfaces

The evaluation shows that alongside targeting the requirements of the elderly in terms of content, it was primarily target troup-oriented operation which would be key to the success of the project. The product will only be accepted right from the beginning if it is simple to use and manages not to make users feel out of their depth. To address these needs, the hardware selected for SilverGame comprises a combination of the familiar with the new.

SilverGame is based on a mini PC or a high-performance set-top box which is pre-configured and is delivered ready equipped with games. It only needs to be connected to a TV set and linked up to the internet using a cable or W-LAN. Simply pressing a button launches the multimedia platform and guides users step by step to the content they wish to access.

The content is displayed on a conventional TV set. This is a piece of equipment which will be available in practically every household and is something the elderly in particular will be very familiar with. Its size also makes it ideal as a central output device. One drawback to using the TV set is the remote control. Generally, modern remote controls have an array of small buttons which older people find daunting. SilverGame will replace this by a handy tablet PC with touch screen which acts as a remote and a game controller in one.

The TV and table PC interact with each other. As soon as the user is able to make a decision, for example which song he or she wishes to sing, the available options are offered in the form of large, clearly arranged buttons on the touchscreen. The user is also prompted to use the buttons on the touchscreen by a message on the TV screen.

The benefit of the touchscreen compared to a conventional remote lies in its contextual control capability: Users are only ever shown a manageable number of "buttons" – the ones which are specifically required for the current operation.

Overall, this approach results in a system which is simple to install and use, and which offers a new and positive user experience – in particular for older people - through the combination of TV set and tablet PC.

3.2 Technical Concept: Innovative System Architecture

The SilverGame project partners are working to develop an open platform for interactive multimedia applications and web-based information and communication services. Alongside the set-top box, the TV set and the tablet PC, the basic equipment includes a webcam, a stereoscopic vision sensor and a microphone. Optional extras include the integration of additional sensors into the platform such as a steering wheel or additional movement sensors.

The platform encompasses a gaming environment modelled in Unit 3D by Exozet. This additionally offers scope for integration of news and content via a content management system. These messages can be designed in the form of text or sound and picture recordings. To supplement the messages, direct communication is possible with individual platform users by video conference link or voice over IP.

Using a web interface such as RSS Feeds, it is also possible to integrate messages and content from external providers.

The technical concept of the multimedia platform has been deliberately kept simple. It centres on a conventional TV set. This is supplemented by a set-top box which incorporates the actual intelligence and consequently enables control of the SilverGame platform. The set-top box is used to integrate all the supplementary hardware equipment into the SilverGame platform. To simplify operation of the SilverGame platform and applications, a tablet computer (such as the iPad) is used as a remote. Additional information can be displayed on the tablet screen.

Fig. 1. Shows an overview of the system components and multimedia modules

By integrating a webcam into the system, contact can be made and gaming interaction can take place with other users or family members, friends and acquaintances using an easy-to-operate video conferencing functionality. For the driving simulator, a driving cockpit can be additionally connected, or for the dancing and dancing and exercise module a special vision sensor. To accommodate these various devices, from the outset the set-top box is equipped with Ethernet, WLAN, Bluetooth and USB ports, guaranteeing that the SilverGame platform is capable of simple future retrofitting to include new applications.

The set-top box is a mini PC running a standard Windows operating system (currently Windows 7 Home Edition). This ensures that new technology can be simply integrated into the platform. Any integration takes place in the central layer which comprises the various drivers for the devices used. At the same time, these drivers function as programming interfaces for the actual modules of the SilverGame platform themselves (upper layer).

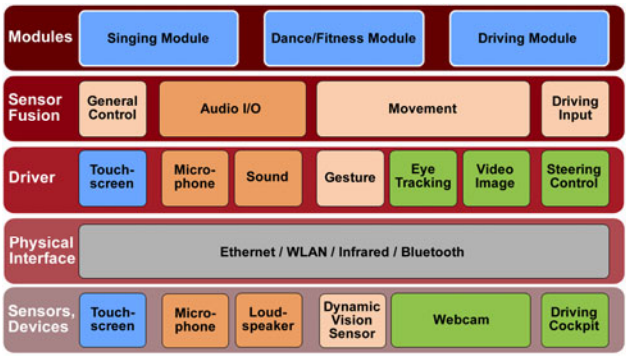

Fig. 2. Illustrates the layered structure of the software/hardware platform using a schematic diagram. The platform comprises five layers. The lowest comprises the connected supplementary devices used for the different modules. These supplementary devices are connected by ports (second layer) to the set-top box.

Between these can be an optional additional layer which can be used for sensor fusion. The sensor fusion layer permits different individual sensors to be merged. The captured data will be combined, analyzed and then made available to the module layer.

3.3 Platform: Online Functionality

SilverGame is an online platform whose core component is the SilverGame server. This features a wide range of independent server components for all the platform areas. The exchange of audio/video data, for instance, does not take place directly between users, but instead distribution takes place via a distribution component on the server.

3.3.1 Video Communication

As one communication element for social interaction within the Silvergame platform, Fraunhofer FIRST is developing a video communication module. The video communication is integrated into the graphical user interface of Unity 3D over a plug-in structure. Thus it can be started and aborted during an established internet connection. For sending of audio and video data (AV data) and establishing and disassembling of the communication (session handling) a server based approach was chosen (see **Figure 3**). That means that the interchange of data is not carried out on the direct way between users, but the circulation is done over a distribution server. That approach gives the advantage of a fixed way of communication and the easy configurability of a network saved with firewalls. The client side implementation of the audio-video communication is based on the Microsoft DirectShow technology. It is easy to combine particular components of the audio and video processing chain by the use of that technology.

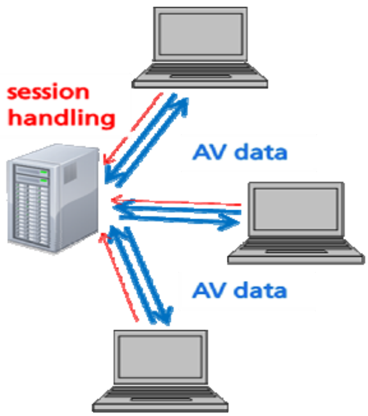

Fig. 3. Session handling of AV data streams over the distribution server

To hold the bandwidth of the communication data within the bounds of the available internet connection (for instance DSL), the audio and video data will be compressed. Therefore the audio compression the GSM 6.10 encoding and for the video compression the MPEG-4 encoding is used. The establishment of the connection was realized using components from Montivision (network DirectShow filter)[1] at this time. The transfer of AV data from the client to the server takes place across a connectionless network protocol (UDP). In contrast to that, the session handling (from the server to the client) is realized via TCP.

Using a distribution server opens the possibility to send the AV data to multiple recipients without increasing the charge of data. The distribution of the data streams takes place on the server. Video data could be saved, played-back or sent to other users of the network. The video communication module has its usage in all three modules of the Silvergame platform. It supports the direct communication between users, the opening of singing sessions by the choir leader, at the instruction of the user during the driving training or at the practicing of new dancing choreographies.

As well as communication between users, the main task of the server is to provide content already made available by users or by the Content Management System.

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[1] Comparing Montivision Development Kit,
`http://www.montivision.com/de/products/`

3.3.2 Editorial Content

For the editorial content, a Content Management System (CMS) developed by Exozet is used. This is operated using a web browser and permits new content for the SilverGame platform to be accessed in a few simple steps. This is designed not to focus only on expanding the system to include new components, but rather to promote communication between users, through active advertising of the latest planned leisure activities, joint meetings or outings – also outside the SilverGame platform.

As well as new dance exercises or singalong songs, SilverGame offers the technical facility for users to upgrade their own systems by adding new modules, or supplementing existing modules with new content. The offered content is supplied in the HTML form or from external sources (such as RSS-Feeds), and can be generated and managed in just the same way as the other content using the CMS. By integrating a simplified web browser into the Unity 3D engine, which an be operated using the touchscreen of the tablet PC, users can subsequently view the content directly at the TV and purchase additional offered material which is then installed automatically.

3.4 Modules: Sensor-Based Feedback

Sensors and analysis form an essential component of the individual SilverGame system modules. Some examples of the currently developed platform modules are described in the following.

3.4.1 Karaoke / Singalong

For the Silver Song Club a feedback algorithm was developed by Fraunhofer FIRST which would allow users to evaluate the accuracy of the user's own voice. Using the karaoke-mode, the user has the opportunity to perform a singing lession and to get a feedback on his singing in real time as well as an overall assessment at the end of the session. The algorithm compares the signal that is sent to the speaker and the signal that is recorded via the microphone. The speaker signal is the target signal and the singer is encouraged to sing along.

To use the vocal analysis the signals have to be preprocessed. Every melody part in the signals is Fourier transformed and to determine the power in a linearly arranged frequency axis the absolute values are squared. Powers of the same tone in different octaves were added such that it is irrelevant in which octave a tone is sung. In the real-time analysis of both, for the expected dominant tone (determined from the speaker signal) and the dominant tone actually sung (determined from the microphone signal) either a red cross or a blue dot is plotted. In another window, only the differences between expected and actual tones are presented which gives a basic overview of the quality of the vocals, but still allows no assessment of the difficulty of the song. At the end of the song, the percentage of correct tones is indicated as a score (0 to 100).

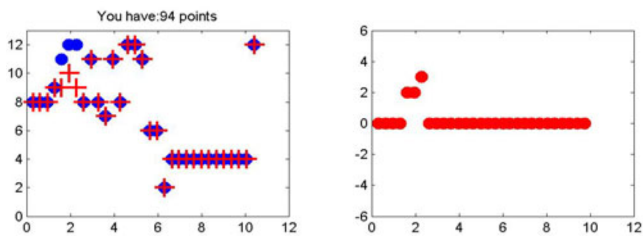

Fig 4. Left: Real-time representation of the expected tones (red crosses) and the actually sung tones (blue dots). The x-axis is labeled in seconds and the y-axis is numbered with 12 semitones starting with a C. The reached number of points.

3.4.2 Dancing/Exercise

The objective of the dancing/exercise module is to train the participant's motor skills through play. This is an essential aspect in maintaining and even improving mobility into old age. To appeal to less mobile users, special exercises are also offered which can be practised sitting down. The exercises are carried out to music, while for the dance routines special choreography is in preparation to suit different musical tastes.

In order to obtain the necessary feedback, a new type of Dynamic Vision Sensor (DVS) developed by the Austrian Institute of Technology is used [11][12]. The sensor is positioned on the TV set, and the user stands or sits around 1.5 to 2.5 metres in front of it. The exercise is demonstrated by an instructor (shown on the TV screen), and is copied by the participant. With the aid of the DVS, the movements / gestures of the participant are recognized, allowing personal feedback to be provided on how well the exercise was performed. Attention is deliberately focused here on non-medical feedback.

Every fitness/dancing exercise is made up of individual figures which last a few seconds. These are combined to create a choreographed routine. This means that the different figures have to be recognized and their execution assessed. The assessment is not aimed at comparing the execution with that of the instructor, but rather to judge the user's own progress. This is designed to keep the user's motivation and interest to continue with further exercises.

Following an in-depth analysis of the available literature, the Hidden Markov Model method was used in order to allow the different figures to be recognized [13][14]. This entails the figures being imitated by different people several times and recorded. This recorded data is used as the basis for future assessment of the exercises and is stored in a database.

This allows the system to be continuously extended to include new figures, as well as new choreography routines and collated exercises. It is also conceivable that future users could be given the opportunity to compose their own choreographic routes and sharing these with friends or other users.

3.4.3 Driving Simulator

For play-based driving practice, the driving control data (speed, lane position, steering wheel and pedal movements) are fused with the traffic features displayed over the graphic user interface (traffic lights, junctions, other road users etc.) and analysed. In addition, physiological parameters such as the viewing direction and reaction speed are picked up with he aid of eye and head tracking algorithms.

Various eye and head tracking systems have been evaluated to date for this purpose at the Fraunhofer FIRST, and a demonstrator has been developed which integrates the different control signals from the steering wheel, eye and head tracking systems and displays them for development of the evaluation algorithms.

4 Summary and Outlook

SilverGame offers something which is totally unique to date: an entertainment platform which revolves around the requirements of the elderly. It is easy to operate, offers games which appeal to older people and also supply added value, promotes the well-being of the elderly by offering three essential factors: fun, exercise and social interaction.

SilverGame is also a pioneering solution in technical terms. The platform uses technologies from different but increasingly converging fields and links them to create a high-performance system: 3D game development, visual sensor technology, web technology, mobile applications, audio and video conferencing and IPTV. This combination has brought about a technical platform which can be quickly brought to market and at the same time offers scope for further developments in the field of Ambient Assisted Living.

Initial talks with potential cooperation partners for distribution of the SilverGame platform confirm the innovative potential of the overall concept. Set-top box suppliers as well as content providers increasingly recognize the economic potential of the 60+ target group and the possibility of reaching more than just a niche market with products targeted to specific user needs. The prospect of integrating SilverGame into their existing portfolio has met with lively interest.

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A Washable Smart Shirt for the Measurement of Activity in Every-Day life

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Abstract. In this article, a washable measuring system for the everyday detection of activity is being presented and evaluated. The measuring system consists of an ordinary pullover with eight acceleration sensors sewn in at the arms and the torso and integrated detection electronics with a radio module and a interchangeable microSD card. The sensors and the detection electronics are made washable by a waterproof encapsulation. The sensor values are sampled at a sampling rate of 10 Hz. Based on the acquired acceleration data, an activity index is calculated and saved on the microSD card. The system was tested and evaluated on four test subjects after being washed. The test subjects were asked to protocol their activities. The recorded data was then compared with the protocol. Every change of activity in this experiment could be clearly detected. The test subject's posture was also detected correctly. Hence, a platform for further usages such as diagnosis system for tremor, dyskinesia and hypokinesia within the scope of a Parkinson's disease was created.

Keywords: acceleration sensors, activity, movement, smart clothes, washable sensor textile.

1 Introduction

The demographic change takes its toll on the society in Germany and other industrialized nations.

To levy and analyze health-related data is an important characteristic of Pervasive Care. Besides the usual vital parameters, there are also data that permit to get conclusions about the movements of the supervised person. The risk of the occurrence of a cardio-vascular disease (Angina pectoris, heart attack, stroke, circulatory disorders of the legs) is just half as high for people who engage in regular physical activity [1]. The mobility is a complex function which depends on many physical, cognitive, sociocultural factors and the external environment [2]. On the one hand, an impulse for movement is being propagated as a therapeutically concept for the elderly and on the other hand, as a prevention of different diseases [3].

Sensors for motion detection are continuously becoming smaller, cheaper and more accurate. The evaluation of the data delivered by these sensors is also becoming easier. By integrating these sensors in garments and subsequently analyzing the data obtained from them, the movements recorded for the user can be detected and documented. Collecting these data over a long period of time allows characterizing the movement habits of the person. Unexpected changes to these patterns can then be used for early detection of potentially disease-related behaviors. As a result, it is possible to initiate appropriate therapy measures.

2 State of the Art

Intelligent assistance systems are already used in telemedicine in the tertiary prevention for the monitoring of chronically ill people. The future of such systems lies in a better integration into daily life and easier usability, so that they can also be implemented for early detection of diseases and for the reduction of risk factors. In 1990, many leading groups in the area of portable integrated sensors predicted the growing integrity of wireless communication as well as the sensor system in everyday clothing [4]. According to [5], the applications of wearable sensors can be divided into six areas: military, civilian (home care and sports), aerospace, public safety (fire fighting), hazardous applications (mine action) and universal (portable mobile applications).

Nowadays, accelerometers are among the most used sensors for these applications. In [6], accelerometers are used in garments in order to carry out localization as well as activity measurement. In [7], acceleration sensors included in garments are used for rehabilitation scopes, where the movements of the upper part of the body are registered and assigned to a particular movement. The same kind of sensors, also attached to the upper part of the body, can be used for respiratory and heart rate measurements [8, 9]. Furthermore, different temperatures can be classified by recognizing tremor [10].

In [11] a system for fall detection based on acceleration sensors integrated garments is presented. The measurement system is washable. In [17, 18] two sensor integrated textiles are used for the detection of tremor in Parkinson's patients. In [12] sensors are integrated in a pant. So the movements of the hips and legs can be measured and stored on a microSD card.

The position of the sensors on the body is of great importance. In [13], 30 accelerometers were distributed all over the body. It became obvious that not only the number of sensors but also their dependence on each other is very important. The challenge of building sensors in garment is that the electronics can’t disturb the user and, on the other hand, to provide the necessary stability, so that the electronics aren’t harmed during normal daily life movements. This leads to the conclusion that the integrated sensors should not be tight-fitting to the body. In [14], the influence of loose-fitting sensing garments is described in terms of measurement accuracy when a movement is being detected. A comparison of different systems is portrayed in table 1.

Table 1. Summary of the state of the art

Ref.	Sensor	Application	washable
[4]	NM	None	Yes
[7]	AC	Rehabilitation	No
[9]	AC	Heart frequency	No
[8]	AC	Respiration rate	No
[10]	AC	Temperature	No
[13]	AC	Movement	No
[15]	AC	Movement	Yes
[11,12,16,17,18]	AC	Movement	Yes

AC = accelearation sensors, NM = noise microphone

Most of the presented systems do not integrate sensors in garments [13, 15], applying them directly on the body. They either have to be attached each time with hook-and-loop fasteners at certain spots or are built in specific, tight-fitting vests. The wearing comfort isn't taken into account.

In order to warrant a long-term recording of data, the measurement garment must be washable, making its production more complicated. There is, on one hand, the possibility of using washable and conductive sensor textiles [7, 16], which increases the production costs tremendously. On the other hand, there is the option of an external wiring that has to be removed before washing, which complicates the implementation of such systems in everyday life.
Task

3 Task and Approach

The movements of the arms and the torso are supposed to be detected by a garment with integrated acceleration sensors. The collected data should be stored on a removable storage medium and analyzed by the user. The electronics should be encapsulated inside a washable unit and the system's power supply should be provided by rechargeable batteries. It is very important that the whole system doesn't hinder the movements of the user while wearing it. The accuracy of such a garment to determine movements has to be proven. By building this system, the basis for long-term recording and analysis of transaction data is created.

By applying this system, a detailed detection of activity is possible. The whole evaluation algorithm takes place in the integrated electronics module. A PC is needed just for the visualization of the calculated results. The pullover with the integrated electronics can be washed in the washing machine due to the encapsulation.

4 Dynamic System Concept Description

The pullover (Fig. 1, 1) doesn't differ from a normal garment externally. In its interior, there are eight acceleration sensors (2), which measure the movements of the arms and the torso. The electronics unit (3) gathers these data and saves them with a time stamp on a removable storage medium (4), which can be read and analyzed on a computer (5) afterwards.

The system is powered by a detachable, rechargeable battery box and the electronics installed in the garment are not easily noticeable by the user. The sensors are made washable thanks to encapsulation and connected with a shielded cable network with the electronics unit, which is built in a washable housing and hidden in a pocket. As a result, the measuring pullover can be washed whenever necessary without concerns of damaging the integrated electronics.

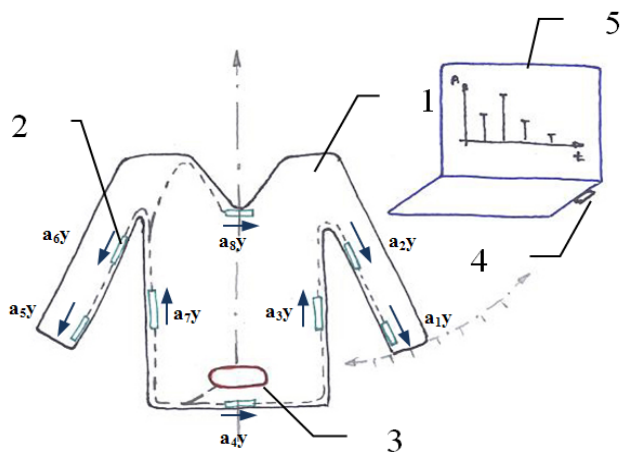

Fig. 1. Description of the system's parts and interfaces

The pullover is dressed just as any other normal one. The data recording settings, such as name, time, measurement duration and software version, are entered in form of a text file on the storage medium (MicroSD card) directly on a computer. The MicroSD card is then inserted into the electronic unit. After the power supply has been ensured by fixing the battery box, the electronic unit reads the saved settings and accordingly sets the desired configurations.

The acceleration data of the eight sensors are being read. From these data, an activity value for every sensor is being calculated. The average of the activity values over one minute is calculated and stored on the integrated Micro-SD card.

If the pullover isn't moved for over 5 minutes, the electronics switches into a sleep mode to save energy. A low battery status can be detected by the electronics. In this case, the data recording is prevented and the user will be informed. At the end of the experience, the battery box is detached and the storage unit can be removed. The data contained in the MicroSD card is subsequently read and analyzed on a computer. Hence, the daily activities of the arms and the torso can be documented and visualized.

The system is characterized by a simple and universal application and a fast and economical production. Additionally, the user is not hindered by the measurement system in his daily life and has the opportunity to wash the garment when needed.

5 Evaluation

5.1 Materials and Methods

In order to define the location of the sensors on certain parts of the body and to protect the cable network, a protective bag made of fabric was sewn in by a tailor along the seam on the garment's inner side.

The 3-Axis acceleration sensor (SMB380, Robert Bosch GmbH) delivers digital values that are read over an SPI-interface. Its measuring range can be set to $\pm 2g_m$, $\pm 4g_m$ or $\pm 8g_m$. The eight sensors are connected to the electronics unit through a cable network (cross section: 0.1 mm^2 with PVC isolation). The electronics unit consists of a nanoLOC module (microcontroller and radio transceiver, Nanotron Technologies GmbH) (Fig. 2, 1), a RV-8564-C2 real-time clock (Micro Crystal AG) (3), a MicroSD-card slot (4), a status LED and the necessary components for power management (2).

The electronics unit is integrated in a washable housing (Polar Electro Oy). The original electrical connections of the housing (press-buttons) are used for plugging the battery-box. The connection between the cable network and the electronics unit is sealed by an encapsulation.

The electronics in this system requires a voltage between 3.5 and 4.5 V. It is provided by a rechargeable battery box (5) that consists of an accumulator with a capacity of 350 mAh, a MAX1555 charging chip (Maxim Integrated Products, Inc.), a USB socket for charging the battery and a charge-status LED.

Each set of activity data is stored in an individual text file with the name ACTIVITY.txt. The configuration parameters of the measurement are saved in another file with the name config.txt, where the device number, software version, time, date and duration of recordings can be set. For this reason, this configuration file has to be updated before valid data recording. Each acceleration sensor will be read with a frequency of 10Hz and a resolution of $\pm 2g_m$.

The integrated microcontroller carries out all the calculations.

Fig. 2. Above: Pullover being used. Below, left side: electronics unit. Below, right side: battery

The obtained data in text format could be directly imported into a spreadsheet application such as Microsoft Excel. Six calculations are then implemented to analyze it. These are:

- Absolute resulting acceleration (|a|):

The resulting magnitude of the three coordinates (x, y and z) is calculated as follows:

$$|\boldsymbol{a}| = \sqrt{\boldsymbol{a}_x^2 + \boldsymbol{a}_y^2 + \boldsymbol{a}_z^2} \tag{1}$$

- Normalization according to Earth's gravity ($|a_r(t)|$):

The value of Earth's gravitation, g_m=9.81 m^2/s, according to the sensor resolution, is subtracted:

(±2g = -512 … +512 : +g = 256)

$$|\boldsymbol{a_r(t)}| = |\boldsymbol{a(t)}| - \boldsymbol{g_m} \tag{2}$$

- Data average ($|a_{rf}(t)|$):

The average of the 10 recorded data (recording 10 times per second, T0=100ms) is generated as follows:

$$\left|a_{rf}(t)\right| = \frac{1}{n}\sum_{t=-n}^{t=1}\left|a_r(t)\right| \qquad \boldsymbol{, n=10} \tag{3}$$

- Average difference ($\dot{a}(t)$):
  For each value the difference to its corresponding average is calculated:

$$\dot{a(t)} = \left|a_r(t)\right| - \left|a_{rf}(t)\right| \tag{4}$$

- Noise filtering ($A(t)$):
  A noise threshold value is experimentally determined and applied:
  Noise value = G = 5 (0.02 g_m)

$$A(t) = \begin{cases} \dot{a(t)}, & \dot{a(t)} > G \\ 0 \quad , & \dot{a(t)} \leq G \end{cases} \tag{5}$$

To calculate the nose value, data from an unworn pullover are being recorded. The average difference (4) is calculated afterwards. A histogram of calculated data has shown that in unworn situations, an activity value of maximum 5 can occur. This corresponds to ±0,02g_m with a sensor resolution of ±2g_m.

By means of this procedure, it can be calculated if an acceleration value resulting from a movement is larger than the noise value. In this case, a activity index can be correctly detected.

The absolute value of the activity index is stored in a puffer. The amount of stored indexes will be calculated every minute. This value for every sensor is a barometer for the level of activities and will be stored on the MicroSD-card.

$$\left|A_{600}(t)\right| = \frac{1}{600}\sum_{n=1}^{n=600}\left|A_n(t)\right| \tag{6}$$

(600 = 10Hz (sampling frequency) * 60 (second))

The outcome can subsequently be scaled by multiplying it with an individual constant factor. This factor has to be detected experimentally. For an objective statement of the calculated values, the position of the person is of utmost importance while the measurement is carried out.

A person who shows a low activity during his sleep has to be distinguished from a person who spends a lot of time on the couch and doesn’t move at all.
The detection of the position just with the help of integrated sensors is very difficult because the garment is loose-fitting. The sensors don’t have a fixed absolute position referring to skin surface. Therefore errors can occur.

In order to minimize the errors, the information from two sensors has to be combined. The acceleration sensors a_3 und a_7 (Fig.1) will be used for the detection of position. The y-axis of the sensors is parallel to the wire. The sensors would ideally measure -1g_m in y-direction, as the person is standing. In x- and z-direction 0g_m would be measured correspondingly.

As the sensors in the pullover are loose-fitting, the two sensors have to be combined with each other and be compared with an offset value (0.8, detected experimentally):

$$if\ (a_3y + a_7y) > -0.8g \quad then\ \ the\ person\ is\ lying$$

With this offset value, the angle of the lying position can be fixed (Fig. 3).

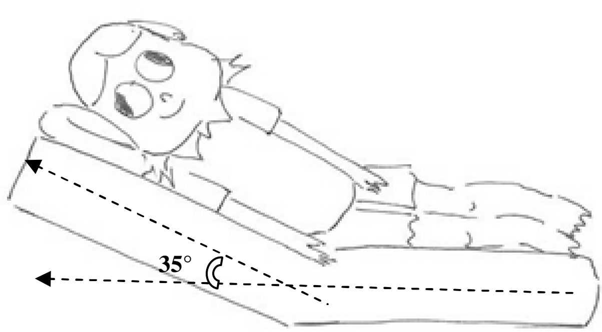

Fig. 3. From an angle of 35°, a lying position will be detected.

If the pullover isn't moved for 5 minutes, the data recording will be terminated and the electronics changes into a sleep mode to save energy. If the garment is moved again, the electronics will detect that movement and re-start the data recording. The flow chart of the algorithm is shown in Fig. 4.

5.2 Setup

The pullover is worn by 4 test persons after having washed it in a washing machine with a protective laundry bag (Wash settings: 30°C (86°F), max spin cycle 1200 rpm). Each test person was wearing the pullover for over an hour, whilst he carries out daily activities. In order to obtain quantifiable measuring results, the test persons receive a list of different prospective activities, e.g. reading, writing, sleeping, watching TV and vacuum cleaning.

The performed activities are documented by the test persons with the corresponding duration. Afterwards, they are being compared with the calculated values stored by the pullover on the Micro SD card.

It is expected that an activity such as sitting and writing a letter can be observed in the stored data. In this case, higher activities of the right arm (right hander) and a relatively

Calm torso are expected. Furthermore it is expected that a young, sporty test person shows higher values of activity than an old test person.

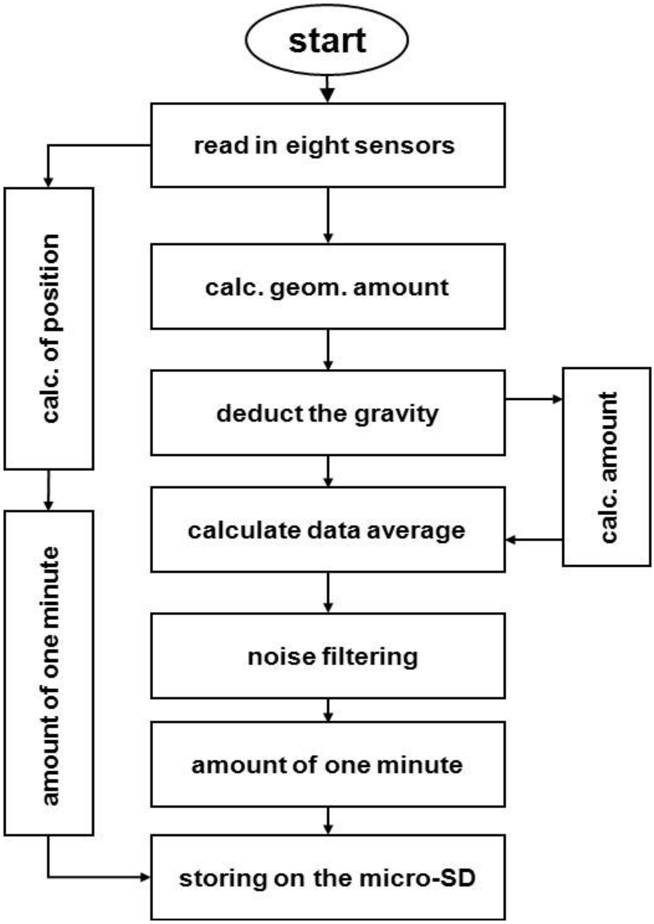

Fig. 4. The flow chart of the algorithm

5.3 Result

The pullover has survived the process of washing successfully. The stored results were portrayed on the PC and were compared with the notes of the test person. It was a correlation between the data and the notice. In the following, the correlation is described with the chosen activities. Thereby, the activity value of 100 corresponds to the activity of a young person during jogging. The lower the value of activity, the less the person is moving.

Test Person A (female, 54 years old and right-hander) notes that she has written a letter for five minutes and afterwards, she went to her car within two minutes. The calculated values of activity on the right and left lower arm and at the torso are portrayed in Fig. 5. As the test person is a right hander, only the right hand is moving within the first five minutes during writing. While she is walking, her whole body is moving.

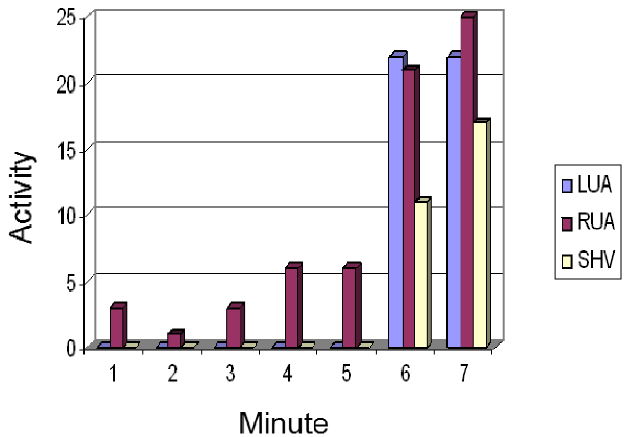

Fig. 5. RUA: right lower arm (a_5y), LUA: left lower arm (a_1y), SHV: neck forward sensor (a_8y), 5 min. writing, 2 min. walking

Test Person B (Female, 83 years and right hander) noted that she had tidied up the kitchen for 10 minutes and had prepared dinner. Afterwards, the person sat down and solved crossword puzzles for five minutes. The calculated activities are portrayed on Fig. 6. It is noticeable that the arms are moving more than the torso. That is typical of the activities in a room such as the kitchen.

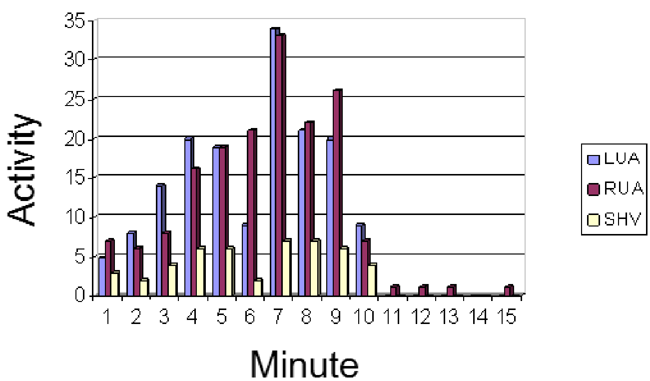

Fig. 6. RUA: right lower arm (a_5y), LUA: left lower arm (a_1y), SHV: neck forward sensor (a_8y), 10 min. Tidy up kitchen, 5 min. sitting and solving crossword puzzles.

Test Person C (male, 29 years old, and left hander) notes that he had eaten for five minutes and afterwards laied down for five minutes. The data are portrayed in Fig.7. The “POS” is a variable for the position of the test person. It is one if the test person is lying, otherwise it is zero. During eating, the test person is mainly moving his arms. The torso is moving minimally. The position of lying such as the activity of the torso and the arms was always detected correctly during this experiment. Consequently, it is possible with the pullover to detect the activity of the arms and the torso. A detailed statement about the kind of activities in view of the detected data was not the purpose of this paper and is not possible at the moment because many activities provide identical values such as walking and vacuum cleaning. Furthermore, the detected values depend on the people and the kind of activities.

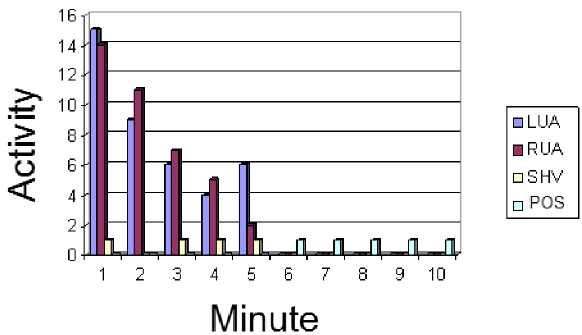

Fig. 7. RUA: right lower arm (a_5y), LUA: left lower arm (a_1y), SHV: neck forward sensor (a_8y), POS: If the test person is lying, this value is “1”, otherwise it is “0”. 5 min. eating, 5 min. lying down.

The improvement in comparison to the usual corresponding gadgets is the washable integration of the sensors in garments, as well as the comprising measuring of activities. Hence it is possible to state if the test person is lying and sleeping or sitting on the couch and playing with the game console.

6 Conclusion

The first prototype of a washable measuring pullover was developed and tested. The measuring pullover consists of eight acceleration sensors on the arms and the torso. The sensors as well as the corresponding electronics are made washable due to encapsulation. The sensor values of the arms and the torso can be averaged over a minute after being measured with a frequency of 10Hz. The activity values as well as the position data of the test person can be stored on the integrated Micro SD-card in text format.

With these data it is possible to detect an alteration in the activity of the test person. An alteration can eventually reveal the beginning of a disease. This information could help the physician to make a suitable diagnosis.

The measuring system was tested and evaluated with four people after having been washed in a washing machine. The test persons were asked to note their activities on the side. This notice was compared to the measured results afterwards. The position of lying such as the activity of the torso and the arms was always detected correctly.
In the following works, the detected movements are supposed to be analyzed in detail with pattern recognition. Various activities could be detected definitely.
With detailed analysis of activities, many diseases such as epilepsia, dyskinesia and hypokinesia can be diagnosed and supervised automatically.

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The scope of the research consortium is to develop technology based solutions which will help elderly people in their future living environment comprising home and workplace as well as in communication and transportation. Eventually not only elderly people but also all social groups should profit from these solutions.

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Part VIII: Community Conclusions

How to Overcome the Market Entrance Barrier and Achieve the Market Breakthrough in AAL

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Abstract. Since the changing demographics the European Commission as well as near all national funding organisations see the necessity to support assisted technologies through huge funding instruments. Despite its tremendous market potential, AAL (Ambient Assisted Living) is still on the cusp of a mainstream break-through. A lack of viable business models is considered almost unanimously to be the greatest market obstacle to a broad implementation of innovative AAL systems. This paper describes the sustainable approach by universAAL and AALOA to overcome this market entrance barrier by mobilizing the AAL community and influencing the funding programs to achieve the market breakthrough in AAL.

Keywords: Ambient Assisted Living, market potential of AAL, business model, AAL reference platform, standardization, market breakthrough.

1 Reason for the Lack of Business Models

Ambient Assisted Living (AAL) has great potential to positively influence the lives of many people. But the impacts so far have been less than hoped, partly due to fragmentation of research efforts and the lack of a standardized approach for developers [1]. It seems unavoidable that the socio-demographic effect will lead to massive costs for care giving in the future. Thus the intergenerational pay-as-you-go pension plans in Europe will be no longer practicable in their current form. Therefore it is obvious that future demands for social support, health and care services can only be satisfied with supporting application of technology.

This effect motivated a lot of research projects to develop prototypical singular AAL solutions in the past few years. Thus AAL has developed to a decisive paradigm for the scientific and market-oriented research aiming at the aging population. Related marketing activities now appear to be ready to start since the first projects are now in their final stage. But there is no functioning market for AAL applications yet and a lack of business models to motivate cooperation between ICT developers, service providers, medical device manufacturers and housing industry is still missing and thus named as the greatest market barrier [2]. This is caused through the high costs of singular solutions which dominate current practice. A BMBF-sponsored study of AAL market potential and development opportunities shows the very unfavourable cost-effect ratio of 17300 Euro per additional year of life expectancy [3]. But since elderly individuals usually have more than one medical disease, these costs will increase dramatically [4]. Hence the only realistic option to minimize overall costs is to cover the aging person's entire clinical picture and individual needs by a unified extensible system. Existing singular products and services must become part of this overall solution.

Since currently dominating singular proprietary solutions use incompatible data exchange formats and protocols, the components of one application cannot be used by another without modification. Configuration by an expert system integrator is required to combine new and existing partial solutions, thereby making the total end solution prohibitively expensive [5]. Additionally, using combinations of singular solutions that are only available as complete packages, it is evident that sensors and other hardware components, as well as individual functionalities, must be frequently installed and paid multiple times. Fundamentally, current AAL solutions, such as building infrastructures with sensors and actuators, require detailed planning and installation by specialist experts. This causes to the enormous costs of today's single solutions which are too expensive for private buyers as well as health and care insurance providers. Unfortunately a lack of business models is the implication of this process and leads in the actual awaiting position of the industry [6].

2 Last Approach for a Unified European Open Source Platform

Since todays singular solutions cause these unaffordable costs there is an obvious need for complete, comprehensive solutions within an overall approach, where various technology and service providers develop individual products that can be easily integrated instead of having monolithic proprietary concepts. Future AAL solutions must be based on a flexible platform that allows a step-by-step expansion as plug-ins to achieve customization to the individual's needs, lifestyle and health progression [7]. That's why the European Commission has funded several platforms for self-organization of devices, sensors and services ensuring ad-hoc interoperability at the semantic and process levels like SOPRANO, AMIGO, PERSONA, MPOWER, OASIS. But since the community in each of the projects had been too small, all these solutions have not achieved the desired market breakthrough [8,9].

This was also recognized by the European Commission. That's why the current framework program decided to support one additional last research project developing a unified European open source platform for AAL systems, the EU-IP project universAAL [10] which combines the eight most promising semantic middleware platforms of the past several years by collecting, comparing, harmonizing, merging and prioritizing the engineering results from the eight input projects.

To get a real chance of success universAAL additionally spent a lot of effort in community building for the different AAL stakeholders and activists. Calls for proposals combined with respective money awards shall motivate scientists and companies worldwide to develop plug-ins to promote the platform's distribution. In various project-related workshops, experts shall be consulted to early unveil deficits in the on-going work to continuously improve the platform. Developers can find or share specifications, development tools, sample programs, and add-ons in an online developer depot. Additionally, the AAL community will be provided with AAL services through an online „uStore". For end users this online store will become a kind of market hall, where everybody can search for suitable solutions and compare them with other users at their leisure. Platform-related standardization suggestions are made to relevant standardization bodies [11,12].

To motivate as much as possible of the stakeholders to join this community a project neutral organisation has been established serving as a meeting point for various projects, individuals, and organizations: AALOA – the AAL Open Association, which is a growing community, officially launched during the AAL Forum held in Odense, Denmark, on September 2010, by researchers from different domains who had subscribed the AALOA Manifesto. The mission of AALOA is to create a shared open framework for developers, technology and service providers, research institutions and end-user associations to discuss, design, develop, evaluate and standardize common service platforms in the field of AAL [1]. The AALOA Manifesto defines the rationale around which several European projects decided to join their efforts. It is a call for action addressing all stakeholders working in this area. A key point of its Manifesto is that transversal cooperation over diverse market segments is really needed to reach the AAL market breakthrough. The proposal is to develop an open and shared software infrastructure to be used as commodity by many stakeholders. To this end, AALOA is following a bottom up process with SMEs and research institutes aimed at reusing legacy software developed in national and international research projects. In order to encourage collaboration, AALOA is organized as a federation of projects, independent as far as design decisions and internal organization is concerned, but sharing infrastructure and resources to increase the visibility and adoption of their own findings. A second important process will be the promotion of projects directly proposed by the governance body of AALOA. This process will be initiated as soon as AALOA has achieved a consensus on the needed infrastructure, namely a common set of guidelines, software interfaces and basic components on top of which to realize AAL services. To this end the converging interest of many stakeholders will be pursued in a transparent and open way by shaping AALOA as non-profit organization.

Therefore, the AALOA initiative can be understood as an invitation to join the mission of bringing together the resources, tools and people involved in AAL within a single forum, making it much easier to reach conclusions on provisions needed to design, develop, evaluate and standardize a common service platform for AAL. In the meanwhile, over 120 individuals from 74 different organizations as well as the consortia of 8 EU projects have announced their support for AALOA's approach. This brings the vision of a unified universal platform a significant step closer to reality because communities of users and developers can be formed around promising RTD results, such as the universAAL platform for AAL, that can ensure continuous support and persistent on-going refinements also after the end of the original project.

3 Unifying the AAL Community

As one of the latest activities, we can mention the AMB'11 workshop on "Support for companies developing AAL solutions to achieve the market breakthrough" [13], which was organized by AALOA and the e-Inclusion Initiative of the European Commission. This event has taken place in June 2011 in Brussels with 42 participants including 20 representatives from private sector to overcome the market entrance barriers. The idea was introduced by Wichert [14] assuming that the European Commission would share the same opinion about the importance of infrastructure solutions adopted widely for the success of AAL in real life. Even though universAAL has tried to incorporate several mechanisms like open source development, the consolidation process, the uStore & developer Depot, and the exhaustive strategies for community building, Wichert was strongly in doubt if these measures alone would be sufficient for achieving the AAL market breakthrough in the next years. Now that universAAL is there with all its claims and the raised expectations, it is getting more and more crucial that the chance for creating an ecosystem around an open common platform is not gambled away. In fact, if universAAL fails, it would be much harder to start a new comparable effort later. Albeit admitting that with its instruments, universAAL can reach the goal to build an open community, Wichert warned that this community could remain limited to universities and research institutes from outside the consortium if no targeted work is done that motivates the industry and the SMEs to develop components and services on top of the universAAL platform. He concluded that there was still need for complementary steps beyond the project’s own instruments in order to grow to a de facto standard used for developing AAL products and services at least in Europe. Creating incentives for the industry and the SMEs to follow the common platform approach of universAAL, however, needs help from the European Commission at the policy level. As an answer to this challenge, he developed the idea of porting projects in which prototypes developed within funded AAL projects should be ported to open common platforms, such as universAAL, in order to create a critical mass of interoperable products and services based on new funding instruments targeted at achieving market breakthrough.

4 Preparation of the AAL Market Breakthrough

As a first approach to achieve the market breakthrough, the goal of the AMB'11 workshop was to involve the industry in new funded projects where their products can be ported to a promising platform solution from international research projects and be integrated in AAL environments with minimal integration efforts. Even if the idea of porting projects had its roots in the community expectation from the universAAL platform, obviously the other initiatives besides universAAL that continue to propose their own innovative platforms for AAL cannot be ignored either. The organizers of AMB’11 indicated this by talking about candidate platforms in general. From the viewpoint of consensus building in the community, porting projects can therefore be classified as a sort of stress testing of the candidate platforms that should deliver the evidence that they are effectively applicable in real production settings and can achieve breakthroughs in terms of widespread availability and deployment of AAL solutions.

Furthermore, the benefits of these projects would be: The industry and research are supposed to get closer to each other, bridging the gap between the AAL research achievements and the industrial AAL products and services. The vendors of the AAL products and services will be able to adopt selected technologies from the latest research results and, if the whole target platform proves to be very promising, will benefit from being among its early adopters [13]. The candidate platforms will be provided with the most effective feedback loop for taking corrective actions and will have the opportunity to deliver the evidence for the practicality of their provisions. The funding authorities (eInclusion [15] and AAL Association AALA [16]) benefit from the overall effect of getting closer to the AAL market breakthrough and can show the usefulness of all the previous investments in AAL.

In alignment with the European Innovation Partnership on Active and Healthy Ageing [17], the main motivation behind the workshop was to discuss the form and content of possible new funding measures from the European Commission and AALA aimed at involving companies in practical experimentation with new technologies currently under development, and offering them the opportunity to influence this work to match their needs.

The underlying motivation for the workshop was the potential for significant economic and social impact from the introduction – on a wide scale – of innovative AAL solutions. While this potential has been recognized for some time, breakthroughs in terms of widespread availability and deployment of solutions have yet to be achieved. The EU and AALA have funded activities in this area for some years, and some of these are now at a stage in their development where direct hands-on involvement of development companies is the best way to make sure that this work produces results that are effective and applicable in real industrial settings. The workshop followed the idea to evaluate funded European projects for partnership in porting a wealth of applications to candidate platforms as an instrument to have such platforms show their practical usefulness, to spread the knowledge, to create an initial portfolio that helps to penetrate the market, and to seek consolidation opportunities.

As outcome by the participants of the workshop some barriers had been identified like (1) R&D projects are not sufficiently driven by a demand-supply approach, (2) SMEs would not be able to invest if there is no stable ecosystem giving them the chance to survive, (3) the desired ecosystem has not emerged yet due to interoperability problems; open platforms must therefore deliver the evidence to have addressed this effectively, (4) Technology and operation cost should be sufficiently low so that investment concentrates on creating products and services that stimulate the market, (5) IPR issues could be an obstacle to open source approaches unless appropriate governing rules apply, e.g. when contributions are provided voluntarily and the results are exploitable freely by all and (6) to achieve sustainability of the open source community a suggestion was made to fund a foundation for managing a global community that works on the maintenance and further development of an open source platform for AAL. The foundation is supposed to be responsible for ensuring a level of compliance that would guarantee quality and trust.

The discussions led to the following conclusions: Research programmes lack support on pre-commercialisation and R&D for ecosystem building. There is need for funded activities that bridge the gap between R&D and product launch / deployment (particularly for SMEs), including the following aspects: ecosystem design, stress testing of platforms supporting such ecosystems (e.g., in living labs), ecosystem compliance and interoperability tests, ecosystem marketing, tool support, lean development process and lifecycle management of products, and education and training for developers and installers.

The demand-supply approach should be applied to separate ecosystems, for instance the social ecosystem where demand is represented by care providers, carers, and end users, supply is represented by application developers and service providers, and public authorities and insurances may act as catalysts; and the technology ecosystem where demand is represented by application developers and integrators and supply is represented by platform technology providers.

Open AAL platforms will create more market opportunities by a true cross-application approach allowing the combination of assistance with eHealth, energy efficiency, safety & security, mobility, etc. in coordination & cooperation with standardization bodies, and by providing a certification programme.

Benefits of porting projects were confirmed; the idea of horizontal projects in funding programmes, in particular in the AAL JP, was born; the community is supposed to document this idea and propose it to the policy makers.

5 A Common Declaration for European Policy Makers

The necessity to address the societal challenge of ageing in Europe has led to a comprehensive on-going R&D program for AAL, which is now an integral part of the Digital Agenda for Europe: the 7th framework program funds longer-term R&D, the AAL Joint Program is dedicated to market-oriented R&D, and finally the ICT Policy Support Program within the Competitiveness and Innovation framework Program supports initiatives related to deployment priorities. One consequence of this has been the emergence of a well-structured European R&D community, as exemplified by the growing success of the annual AAL forum event [18].

The European Commission is also in the process of defining a strategic implementation plan for a pilot European Innovation Partnership on Active and Healthy Ageing that aims to increase the average healthy lifespan in the EU by 2 years by 2020. This plan should be finalized by the end of this year. Since AAL will be an important part of the plan, comments were made by members of AAL community on the need to improve the research program in order to bridge the gap between R&D and products, pointing out that many R&D activities focus on heterogeneous proof of concepts while insufficient attention was put into overall co-ordination.

It was agreed between AALOA, e-Inclusion and the AAL Association AALOA that the community should continue to discuss in order to agree on a set of proposals with concrete action points that would be ratified during the AAL Forum in Lecce last September, so that the results could be provided to the policy makers, more concretely to the EIP-AHA steering group [15], European Commission [16], and AAL JP [17]. Thus the community joint the AALOA approach after the workshop mentioned above and started with discussions how to make suggestions to the EC policy makers who are currently defining a strategic implementation plan for a European innovation partnership dedicated to active healthy ageing. The participants of the workshop had joined a dedicated AALOA mailing list. The mailing list has also agreed on the following action points that should build on the workshop results: (1) seek the widest possible consensus on a declaration that would call for the implementation of a number of key measures for the advent of AAL. This initiative should be endorsed by a significant number of AAL projects (FP7, AAL JP, CIP, ITEA, national projects) as well as related key organisations / associations to maximize impact and (2) create a more concrete specification for horizontal porting projects in funding programmes, in particular in the JP, possibly to be attached to the declaration, as an example of a concrete step towards filling the gap between R&D and product launch.

6 The Lecce Declaration: Influencing Future Funding Programmes

All these contributions has taken the shape of a declaration made public during the AAL forum in Lecce in September 2011, which was subsequently proposed to delegate to AALOA and that was made public and discussed in a dedicated workshop during the AAL Forum event in Lecce. The governing board of AALOA set up a declaration organizing committee that worked on a draft which was then discussed in the AAL forum website in five consecutive versions which have been supported by 42 projects and organizations [19].

The declaration is around the use of an open platform. A platform can be defined as a computing architecture including software and hardware that serves as a foundation to application programmers. Since it separates specific features implemented by a small community of system experts from application features implemented by a larger community of developers, it allows much easier development of applications.

But the creation of an ecosystems based on a common platform involves long term support and coordination issues. There is a need for long term coordination to allow the integration of transversal features such as quality of service, liability, security, privacy, trust, quality of service, scalability. Such features are developed by in other R&D programs. In particular coordination with other non AAL platform developments is needed [18]. Additionally there is a need for long term coordination between research and products. AAL platforms should allow for the integration or novel features that are maybe not yet ready for deployment. The research program is vast and long term. It has to cope with many research challenges: the integration of research features into a platform that meets research requirements, and the integration of components in a platform that meets industry requirements. Furthermore there is a need for long term coordination on interoperability. Given the complexity and diversity of the domain, interoperability is a challenging feature to integrate into AAL systems. Individual collaborative projects need to be coordinated according to an interoperability framework. Consensus building is needed.

The Lecce declaration workshop had the focus on different types of measures for identification of topics and priorities that can be addressed through today funding instruments, measures which necessitate coordination within the program, and measures which would require changes in the program. Examples of measures will relate to ecosystem building based on a common platform, definition of an interoperability framework based on this platform, long term support of a recognized body supporting the use of the platform in the future ecosystem, and long term support of a consensus building process:

- New funding activities should be directed at bridging the gap between R&D and bringing new products to the market (for SMEs in particular), e.g., by promoting the convergence of similar results into established and reusable concepts, then relating the established concepts to each other in order to provide coherent views on AAL systems.
- New programmes should include items such as stress testing of competing technological enablers (e.g. in living labs), providing tool support, and facilitating lean development processes.
- Some work should be directed at building sustainable ecosystems through targeted work, e.g., on ecosystem design, ecosystem compliance and interoperability tests, ecosystem marketing, and life-cycle management of products and services.
- The sustainability of the common platforms that underpin ecosystems should be promoted by supporting open, not-for-profit associations of stakeholders, such as AALOA, to take on the role of a recognized body that guarantees for sustainability of ecosystems through platform maintenance.
- Work on creating open specifications for building blocks of the envisioned common platforms should be facilitated so that their interfaces and interaction protocols are publically known and agreed upon in the ecosystem.
- AAL platforms should position themselves in relation to other platform initiatives such as the Future Internet PPP. It must be possible to use technology building blocks developed elsewhere in related domains; the AAL community has to avoid the trap of relying on isolated technology that is incapable of being integrated into the wider realm of future technologies.
- A long-term consensus building process should be initiated in the AAL community, aimed at making it possible for applications built on top of common platforms to provide value to each other. In open distributed systems, sub-components of applications will be able to contribute to several distributed applications without even knowing all of them beforehand.´
- Education and training should be developed or adapted to take account of what results from the above recommendations, in order to reduce the long-term uptake costs for stakeholders.
- Efficient IPR management strategies should be developed in parallel wherever stakeholders are supposed to exchange knowledge during the implementation of the above measures, e.g., when dealing with convergence of similar results, reusability of building blocks and their APIs, positioning of AAL platforms in relation to the wider realm of future technologies, and interoperability of applications.

7 Next Steps

The 40 participants of the AAL Forum Lecce Declaration side event had made a ratification of the declaration. The general target and the nine measures were in general agreed.

The next steps will be to contact the EIP/AHA initiative since we identified the need of work in aspects of research and innovation programs towards the implementation of EIP/AHA, where AALOA as one entity could play a role developing a task force.

A meeting in Brussels is foreseen with the national contact points of the AAL-JP in order to create awareness about the need of a platform, which could be hosted at the Commission. This could be a kind of consolidation of the AMB11 workshop but considering the different contact points.

But even the Lecce Declaration was a big success it was only a first step and we are facing a long, rocky road until we reach the enthusiastic goal to overcome the market entrance barrier and achieve the market breakthrough in AAL. But only when industry is ready to develop products and services based on the common unified platform, AAL really will get the chance for success.

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