LivingCare – Ein selbstlernendes, humanzentriertes Hausautomationssystem: Erhebung und erste Analysen einer umfangreichen Datenbasis aus einer realen Wohnsituation

LivingCare – A autonomously learning, human centered home automation system: Collecting and preliminary analysis of a large Dataset of real living situations

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Kurzfassung

Im Rahmen von LivingCare wurde eine reale Seniorenwohnung mit einem umfangreichen Hausautomationssystem ausgestattet. In der Wohnung wurden insgesamt über 60 handelsübliche Sensoren/Aktoren verbaut. Das System sammelt die durch die Sensoren zur Verfügung stehenden Daten rein passiv. Es greift in keiner Weise in den Tagesablauf ein. Alle Aktionen wie z.B. Lichtsteuerung und Heizung werden weiterhin durch die Probanden gesteuert. Diese Daten werden über einen Zeitraum von 18 Monaten gesammelt. Dadurch wird einer der umfangreichsten Datensätze dieser Art entstehen, der bisher aufgezeichnet wurden. Die Daten werden im Verlauf des Projekts die Grundlage zur Entwicklung autonom lernender Algorithmen bilden. In der zweiten Projektphase soll die Steuerung des Hausautomationssystem durch diese Algorithmen erfolgen. Ziel ist es, ein an die Anforderungen der Bewohner angepasstes und mitwachsendes Hausautomationssystem zu erschaffen, das im Alltag wichtige Unterstützung leisten, zur Früherkennung von altersbedingten Verhaltensveränderungen beitragen, sowie wie Notfälle erkennen und Hilfe rufen kann.

Abstract

Within the scope of LivingCare, a BMBF funded research project, a real senior residence was equipped with a large amount of home automation sensors. More then sixty sensors and actors were installed in this apartment. This automation system is working totally passive in the background. It doesn't perform any actions. All actions performed by humans like switching light on or off, setting the temperature and the usage of electric devices like TVs will only be recorded as data and not performed by the system. Such data is collected over a period of 18 months. Thereby one of the largest mobility and characteristics datasets based on home automation sensors will be acquired. This data will be the foundation for developing autonomously learning algorithm. During the second project phase these algorithms should start to control functions of the home automation system. The projects objective is to develop an autonomously learning home automation system that automatically adapts to the resident's behavior. The system will be able to grow with the users needs. With all the possible data collected it will be able to support daily actions, recognize behavior changes over timer and will be able to call help in emergency situations.

1 Overview

The research work described in this paper is taking place in the BMBF funded research project LivingCare.
In LivingCare the individual partners are working on a human centered home automation system to support elderly people in their own homes and to assure a longer and self-sufficient life. To achieve these objective several criteria will be addressed:

- The utilized home automation has to be cost-saving and has to be installed easily in existing housing structures like houses and apartments.
- Design of a novel sensor for detecting a dependable number of persons in a room

- The home automation system will not be driven by inflexible rules but by autonomous learning algorithm

Particular attention within the software development will go to the autonomously algorithm design. The final system system should be able to perform specific actions like turning on and off lights or electrical devices and manage the indoor temperature. To avoid a total chaos through those actions performed by the home automation system in the elderly household it is necessary to test and evaluate those algorithms previously with real data. In the following will be, beside a general project overview, described how the required data for the evaluating process was recorded, analyzed and what information were detectable. The focus will lay primarily on kinesics-behavior and behavior pattern.

2 State of the art

The state of the art of LivingCare contains of several disciplines described next.

2.1 Home automation

Home automation (HA) focusses, as a part of building automation systems, especially on the conditions of private homes and the special demands of the inhabitants. HA sensors and actors are used primarily for illumination, shading, heating, ventilation and air conditioning. Other applications are alarm systems and energy saving.

Existing systems could be roughly distinguished in cable based or wireless solutions. In cable based solution the communication works over a bus. Known standard bus base systems for example are KNX, LonWorks and BACnet. In the case of wireless systems, no construction measures have to be performed. That's why it is much easier to use these systems in existing buildings. Known radio standards are ZigBee, Z.-Wave, EnOcean and KNX RF and other manufacturer specific solutions.

During commissioning the system integrator and the client define rules for the HA system. These rules can be altered later, but not without the system integrator. This is very inflexible. Systems that learn from user input would be more flexible and accepted by users.

2.2 Mobility analysis & Behavior modeling

Personal mobility is an important condition for a self-reliant and social integrated live [1] especially the ability to move with or without technical aids from one place to another. The change of mobility, especially in higher ages, is correlated with health deterioration. Common test for elderly people are gait and balance tests. In many researches technical systems were introduced based on ambient or wearable sensors to determine objectively a persons mobility [2] . Research done by OFFIS in the projects PAGE [3] and GAL [4] have shown, the usage of ambient sensors leads to saving of time in clinical applications and that it is much easier to install such systems at home for preventive and rehabilitative applications. Home automation can be used due its easy installment for those applications, too as shown in [5][6][7][8][9].

2.3 Statistical Data Mining and stochastic Processes

Methods of statistical data analysis are used to gather knowledge of process data. Analyzation of sensor data allows to classify situations and is a starting point for context sensitive, software driven services. The process of knowledge discovery can be separated into the Phases of providing data sources, target definitions, data selection, data cleansing, data reduction and transformation, process model selection, data analysis and knowledge interpretation. For pre processing the following filter techniques are known: polynomic based approaches like Savitzky-Golay, outlier tests by Nalimov, Walsh or Grubbs. For multivariate datasets Andrews-Curves, M-estimator or Stahel-Donoho-Outlyingness are suitable to find artefacts and abnormal process-sizes. Besides the reconstruction of not equidistant data series and the determination of missing values the process data classification with the assistance of methods like k-means, Maximum Margin Clustering or EM-Clustring are the steps following after data analysis. To determine process paramters (e.g. Gaussian Mixture Models) for stochastic models methods of descriptive and explorative statistic are used. The methods main objective is the identification of features vectors that can be associated with states of probabilistic automats (SD HMM- State Duration HMM). That's how Hidden Markov Models and Relational State Descriptions for modeling spatial and temporal states could be used. Posture- and gesture recognition based on HMMs where subject of discussion in [10]. The recognition of human activity with in the AAL domain with linked HMMs was subject of discussion in [14][15]. Metodical approaches are pursued by [11]. They address histogram based Training. [12] address the training of HMMs of second order with the help of multiple observation sequences. State Duration approaches are proposed by [13].

3 Own approach

Home automation, as used today, is an inflexible entity. Once it's programmed it performs always in the same manner. State A leads always to state B. The advantage of a deterministic system is its behavior is predictable and errors are easy to recognize. In LivingCare the system is supposed to adapt autonomously to the users' needs. It should grow with the rising and changing needs of its user to secure the possibility to stay at home as long as possible. That is not possible with a system depending on inflexible rules. That's why the home automation system in LivingCare should be driven by autonomously learning algorithm.

This provides some advantages:

- Behavior change will be recognized in an earlier state. So it will be possible to react in time when, e. g. the person stops to prepare meals or using the shower.
- The system will be able to adapt to new behavior and support the inhabitant as best as possible.
- In a possible later commercial version service will be much cheaper because it is not required to call a technician for every small system adaption.
- It is possible to install all components at once but only required modules or functions are activated at first and then piece by by piece according to the the users needs.

An autonomously acting system may cause plenty risks. If the system does not work as expected it could cause serious harm to the user. That must be avoided at any circumstances.
The autonomously learning algorithm are based on reinforcement learning methods. The algorithm will monitor the inhabitant behavior for a certain time and learns their habits. After the learning phase first actions will be performed, like switching on lights or adjusting temperature. Each performed correction action by the user will be recognized as negative feedback. The algorithm will adjust its calculations and try another strategy next time. In addition, the system will only be able to act in tight boundaries. The temperature for example will only be adjustable in a specified range or the algorithm is only able to turn on lights but not to turn off to avoid injuries.

3.1 Scenarios

To keep the project manageable, it was essential to identify some important scenarios that would provide a real benefit for elderly people in their homes.
The team identified these scenarios:

- **Needs-oriented illumination:** Illumination will be set according to the users needs. These needs will be derived from the user habits and external factors. The system learns to link both information sources together and will use this information to generate an optimal illumination scenario.
- **Needs-oriented indoor climate:** the home automation system provides everything needed to control room climate. In combination with habit studies the algorithm will be able to provide the suitable room climate for every situation. Particular persons will be able to control the temperature via Internet.
- **Movement sensitive alarm:** The system will recognize absence and sleeping times. If one of both states is identified a burglar alarm is automatically activated.
- **Safe Mode:** If the user leaves the home for longer time, the system will shut down all devices the could cause fire or will waste energy, like stoves or electric irons.
- **Monitoring of morbit adults:** The used sensors allow to monitor resident behavior. The Occurrence of abnormal behavior, like reside to long in the bathroom, could be identified and lead to an emergency call. Slow changes in behavior could be identified to. If the user spend lesser time in the kitchen day by day can implicate that the person doesn't cook meals any more and an appropriate information could be delivered to involved individuals.
- **Intelligent pill-cabinet:** A sensor, equipped to the cabinet door, will recognize if the door was opened or not. A reminder will be given to the user and if that does not lead the user to take the pills an authorized person will be contacted.
- **Visual and acoustic telephone bell:** Telephone calls will be indicated through light and sound.
- **Mailbox sensor:** a sensor will be placed in the mail box. The user will be informed if mail was delivered by light, sound or a tablet app.
- **Remote maintainable AAL-components:** the system will able to self-monitor. In case of problems it should be possible to fix the system via remote maintenance.

4 Realization

High responsibility rests on the system and the research team. The system must be tested very accurate. The algorithm should be verified against real data. Fatal dysfunction in the real application must be minimalized as good as possible. Behavior data, based on home automation systems, were not available in the amount needed. So it was one of the first tasks to set up a home automation environment in a real apartment inhabited by real people. The apartment should be equipped completely with all conventional kinds of home automation sensors. Data from these sensors will be gathered for about 18 Month. This will result in one of the largest datasets of that kind gathered ever in the scope of an AAL research project. The data will be analyzed and used as learning base for the reinforcement algorithm.

4.1 Test persons/subjects

It is not easy to find volunteers in the picked target group. Elderly people often deny modern technology or are afraid not to understand what happens to them or that they will be overstrained. The Deutsches Rotes Kreuz (DRK) is one oft the project members. The DRK runs a retirement complex in Oldenburg with 68 residential units. The different types of apartments range from small one room apartments to bigger penthouse apartments. The DRK was ask trying to find volunteers out of these apartments for the 18-month field trial. No special requirements had to be fulfilled. It was more important to find anyone who was willing to help. The search was successful. A married couple, living in one of the penthouses was happy to help.

Test person 1 is marked by the following characteristics:

- 75 years old female
- very hale and active
- good mobility
- visits sports groups regularly
- takes dog for walks daily

Test person 2 is marked by the following characteristics:

- 82 years old male
- very restricted mobility
- high risk of falling
- mentally fit
- not as active as test person 1
- light smoker

The usual homework like cleaning up, laundry, ironing etc. is done by test person 1. Once a week test person 1 is assisted by a cleaning lady. Both test persons are technical affine and use smartphones and personal computers. The project background was explained in detail to both. Before installing the sensors both were asked for their approval and the Oldenburg ethic committee was asked for approval, too. Both test persons know they can always terminate their participation without giving reasons. At any time, they will be explained in detail about what data where collected in an easy to understand way.

4.2 The Penthouse

For a field trial the penthouse has a very interesting floor plan (Abbildung 1). The penthouse provides about 80 square meters of living space, divided into two bedrooms, a complete kitchen room, a large living room, a shower room with toilet, a small corridor to separate the bedrooms and bathroom from the rest of the apartment, and much longer corridor with an integrated kitchenette. Furthermore, there are a sheltered Loggia and from both bedrooms and the living room it is possible to get on another roof terrace. The penthouse is situated on the 5^{th} floor.

In the field of accessibility or senior-focused equipment the following features should be turned out:

- Elevator up to the 4^{th} floor
- Stair lift from 4^{th} to 5^{th} floor
- Ground level walk-in shower
- Support rails in shower and at toilet
- To access the loggia a 25 cm high ring foundation must be climbed. Because that implies a high risk of falling a support rail is mounted next to the loggia door.
- Nurse call in the living-room, the longer corridor and both bedrooms.

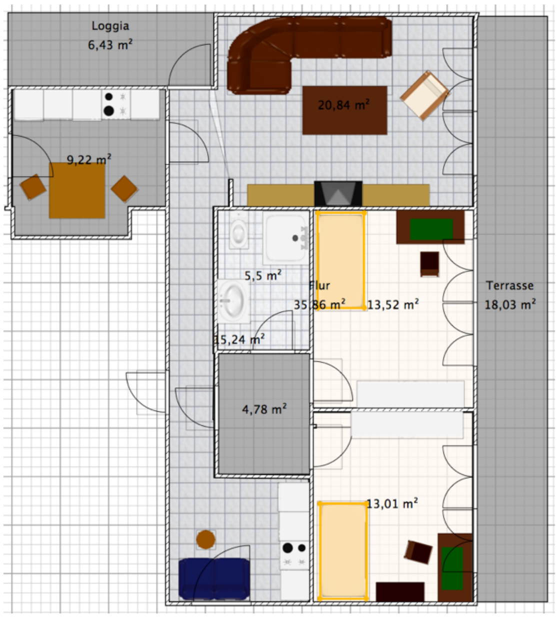

Abbildung 1: Penthouse floor plan

4.3 Home automation

Equipping existing buildings with home automation was a very cost-intensive effort just a few years ago. Those systems normally were linked by cable (Bus) or a special kind of cable installment (star topography wiring) was required. That's why normally only new buildings were equipped with home automation. But the installment wasn't cheap anyway. To equip a single family house with home automation expenses of more than 10.000 € were totally normal. Nowadays much cheaper retrofit solutions are on the market. These solutions are often radio controlled and no additional cables are required. Actuators and Sensors often replace usual used elements like light switches or standard sockets. Switching actuators are so flat they can be used underneath regular components or in junction boxes. Remote controlled home automation has only one small drawback, many components are battery-powered. That causes a noticeable amount of waste over the years. That's the price to pay for easy retrofit components. In selection and functionality, the novel systems are as good as the established systems like e.g. KNX/EIB. Due to the described properties home automation becomes more and more popular, especially in existing buildings and in private homes. Even new buildings were equipped with the much cheaper remote controlled based systems. Instead of costs in the

10.000 € range a fully equipped private home will cause costs around 2 to 3.000 €.

4.4 Sensors

During the field trial, all possible kinds of data should be collected by the home automation system to form movement profiles and detect behavior patterns. To achieve this goals, it is important to specify the used home automation components:

- **Door-/Window contacts:** With these sensors it is possible to detect when windows or doors were opened or closed. In combination with motion sensors it is possible to extract movement directions and speed.
- **Motion sensor:** If motion sensors are mounted correctly they allow to detect presence in rooms and motion paths from one room to another, as well as movement speed. Furthermore, an additional brightness sensor is build into the sensor. That provides another useful information source.
- **Switch actuators:** Used as a replacement for conventionally light switches it is possible to detect when the inhabitant turns on and off lights, in combination with the motion sensors brightness sensor it is possible to draw conclusions about lightning conditions, too.
- **Roller shutter actuator:** This sensor allows to detect the usage of roller shutters and the absolute position, like fully closed or just 50% close/open.
- **Electrical radiator thermostat:** By the use of this sensor/actuator it is possible to detect the actual temperature and the temperatures when chosen by the user.
- **Wall mount thermostat:** the additional benefit to the radiator thermostat is the build in hygrometer and it is possible to regulate more than one radiator at once.
- **Switchable sockets with power meter:** this sensor get connected to electrical devices of daily use like television sets, Microwave oven, floor lamps, computer or the like.

The persistence off all data flows is handled by a base station. The entire system is not connected to the internet to ensure data safety with highest certainty. Every 14 days an authorized person is going to visit the subjects to pick up the data by hand. The correct system functionality is checked at the same time as well as the subjects' satisfaction with the system.

4.5 Installation

Altogether a total number of 64 sensors and one base station were installed to the penthouse. The support of an external electrician was required. The whole process lasted about one day. Another day was used to setup and testing the system.
The complete installation is running since July. Minor problems were fixed expeditiously. In the beginning two wall mounted thermostats fell off the wall, because of to flimsy adhesive. Two screws solved that problem permanently. Another problem was a corridor intermediate switch circuit that doesn't work properly.
In detail the following sensors were installed:

- 10 movement sensors
- 7 electrical radiator thermostats
- 3 Wall mounted thermostats
- 11 Door-/Window contacts
- 12 Switchable sockets with power meter
- 14 Switch actuators
- 6 Roller shutter actuators
- 1 junction box mounted power meter

The only holes were drilled for 10 movement sensors (Abbildung 2) and the 3 wall mounted thermostats. The holes are very small and if required easy to seal, so no visible damage would remain after removal.
The experience made shows, an installation of that kind could be accomplished without major problems. Later commercial systems should cause no mentionable effort.

5 Results

The system is now active for about 4 months without any negative incident and is collecting data without interruption. In that period more then 55.000 events were recorded weekly. The dataset consists of more than half a million records at the moment and is steady growing. Next logical step is to analyze and structure these data. First objective is to develop a data mining algorithm which, based on the recoded data through different substeps, is able to detect sensor activation sequences that represent typical inhabitant behavior. These detected sequences are used as input for the autonomously learning algorithm. In the final project stages the algorithm should be able, based on this data, to recognize typical inhabitant behavior, to detect untypically behavior and detect slow behavior changes. Based on this results the algorithm generates home automation rules that will support the inhabitants' daily life.
Preliminary projects showed, normal behavior and deviations of that behavior could be recognized by observation of activation sequences and duration of sensor events. But without knowledge about the floor plan, sensor installation location and other prior knowledge this method will not work correctly. Different to that prior approach this time the algorithm should work with as less prior knowledge as possible and standard algorithm should be used as far as possible.

5.1 Method

At first an explorative data analyses were undertaken. The objective was to evaluate the information content and to gain a first impression about "recognizable" behavior patterns in the sensor data and to find failures in sensor location and to give optimization proposals. Another approach was to determine the minimum prior knowledge required to recognize behavior pattern.

5.2 Association analysis

Association analysis was used to determine if and what regularly combinations of sensors and sensor data could be found.
The association analysis rules describe the correlation among mutual occurring events. The purpose lays in determining elements of actions that imply the occurrence of other element of the same action.
But in the end, association analysis does not provide satisfying results. It was not possible to recognize related elements reliable. The reason is, the frequent occurrence of certain sensor events in relation to its total appearance does not say anything about its significance. Moreover, the sensor event order differs too much to determine identical sequences.

5.3 General activity

A simple form of behavior at home is to move from one room to another or to stay in a room for a while. To determine Movement and Staying effective, movement sensors were installed that way that every 4 seconds an event was triggered if movement was detected in the field of view.

To be able to make that kind of activity visible, general activity was modeled in that way that the frequency of sensor activations for every hour over a day were accumulated. The more frequently a specific sensor was activated over the day, the more activity took place in that room.

At first the sensor events were filtered on based on sensor types. Only Events triggered by movement sensors were analyzed. Afterwards every event of every sensor every hour per day were counted and the mean value for each day was calculated. The results are shown in fig. 3 in form of a heat map.

As a result, it can be specified that without any prior knowledge, only through movement sensor data analysis, it is possible to make rough statements about the daily activity level of inhabitants.

The diagram for example shows that the kitchen is used more frequently around lunch time and supper time. KBewegung identifies the kitchen movement sensor.

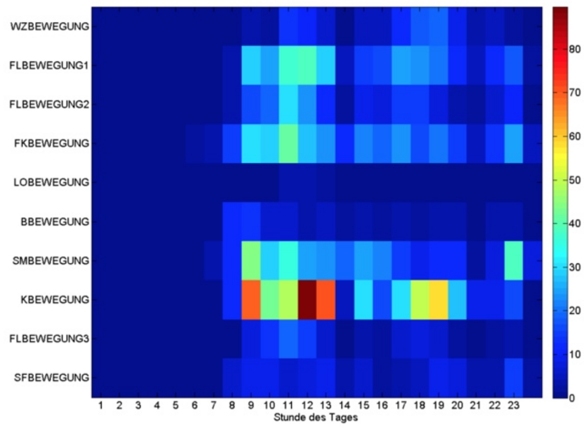

Abbildung 2: Accumulated movement sensor events pe hour over one day.

SMBewegung describes the movement sensor in the bedroom of subject 2. It is easy to see when the person is going to bed and when the person gets up in the morning.

5.4 Activity detection through analysis of electrical parameters

In a previous project "AmbiACT" it was demonstrated that through the use of electrical devices it is possible to recreate daily routines, general activities and abnormal behavior. Therefore, switchable sockets with an integrated power meter were installed at the test apartment. This time, instead of movement sensor events as in the "general activity" section, the events triggered by the power meter were analyzed. The objective was to show if the used energy per measuring point per hour over a day allows to detect general activity and a daily routine.

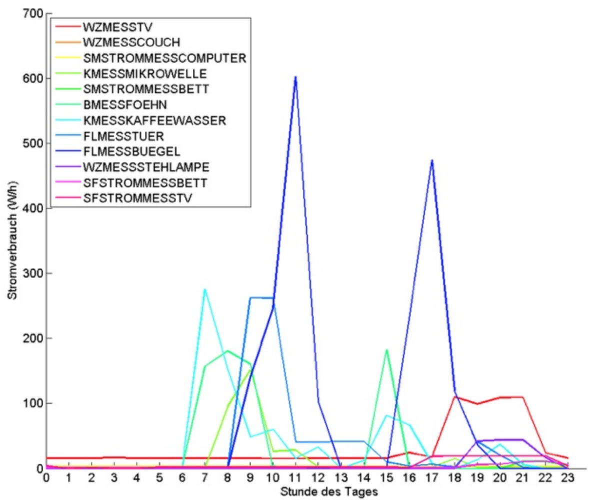

Abbildung 3: Activity detection through analysis of electri cal parameters.

Fig. 4 shows the evaluation results. For example, the red graph WZMESSTV shows when and how long the television in the living room was used. The television is mostly used in the evening hours between 5 p.m. and 10 p.m. The result shows, it is quite easy to conclude that observing energy consumption of specific devices makes it possible to determine daily routines.

But in this case prior knowledge is needed. Without the knowledge what sensor is connected to witch device it is not possible to recognize specific activities.

5.5 Determining occupation times

A lot of accidents at home with seniors happens in the bathroom. The floor is often slippery and when someone falls he or she falls hard. That's why it is important to determine occupation times especially for the bathroom. To recognize unusual long occupation times is very safety relevant for the inhabitants.

So another approach was to examine the significance of movement sensors and door-contacts to determine occupation times for the bathroom. It took no time to recognize that door-contacts alone does not help to determine occupation times, That's because the door is not always closed as the room is in use. But again, movement sensors are very useful for this scenario. Every 4 seconds a movement is detected in the field of view an event is triggered. To calculate the occupation time all events occurring all 4 seconds have to be accumulated. The result is the time a room was occupied without interruption.

Fig. 5 shows the median occupation time for the bathroom. The visualization is carried out as an error-bar graph. It shows the median occupation on the y-axis and the standard deviation on the x-axis according to the hour of the day. The longest occupation time for the bathroom is obviously in the morning hours between 8 a.m. and 10 a.m. The high standard deviation may imply that the shower is not used every day.

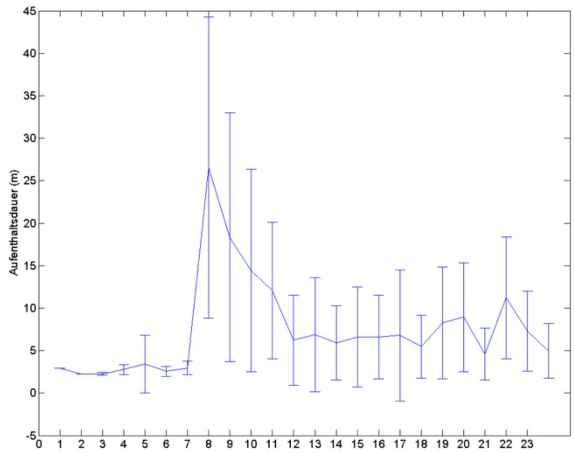

Abbildung 4: Determining occupation times througl motion sensors.

The evaluation showed that it is possible, with the usage of movement sensors, to determine the occupation time of a specific room. If this method would be used as an alarm trigger for to long room occupation, in this example an alarm should be triggered in the mornings after an occupation of more then 60 minutes and 30 minutes for the rest of the day with a low risk of false alarms. The only required prior knowledge is the name of the movement sensor to determine the correct room. The additional analysis of door-contacts does not improve the results.

5.6 Valuation of walking speed and recognition of persons with movement sensor data

Self-selected gait speed is an important indicator for current health problems and an indicator of future problems. Although gait speed generally decreases with age, sudden changes and gait speeds below 0.5m/s are strong indicators of health issues.
To detect gait speed using home automation sensors, we choose two motion sensors that have a long and ideally straight distance between them, and measure the time between sensor events: the area of the hallway between the kitchen and kitchenette is an ideal place for this measurement. We can find the distance between the motion sensors using the blueprint of the flat (Figure 6). Although not all measurements between the two sensors will be precise, as subjects may stop in between, turn around or engage in some activity, using several measurements over a longer period of time gives us an estimate of the actual gait speed.
Although the sensor data does not tell us which subject walked between the sensors, we can apply a cluster analysis on the speed of each measurement. Figure 6 shows that, at least for part of the time, there is a constant occurrence of slow (0.38m/s) and fast (0.78m/s) movements. While we cannot be certain whether both subjects are

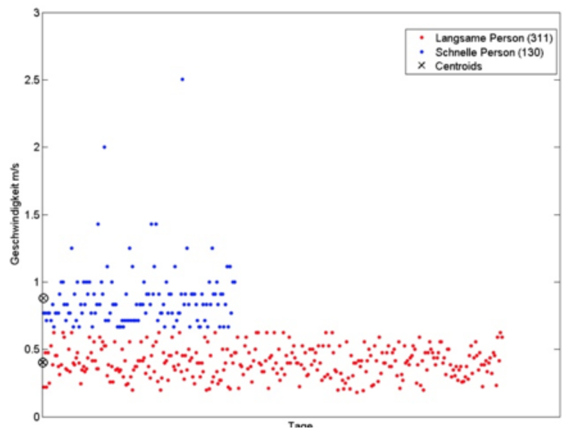

Abbildung 5: custering for the identification of differen movement profiles.

clearly separable using gait speed alone, the findings coincide with our knowledge of the subjects' mobility.

Abbildung 5 zeigt die Visualisierung der Cluster. Auf der X-Achse sind die Messungen in der Reihenfolge des Auftretens abgetragen, auf der Y-Achse die gemessenen Geschwindigkeiten. Die Cluster sind farblich markiert.

5.7 Detection of behavior patterns

Daily activities contain countless short and long sequences, which in part can be found in the collected data. Part of the project is to test the data for discoverable rituals or sequences that, at least in part, can be automated. The current subjects informed us of one particular daily ritual: One of the subjects watches TV until approximately 23h. During this time, the floor lamp in the living room is lit. When the subject goes to bed, he must first turn on the light in the hallway or kitchen, then returns to the living room to turn off TV and light. From the hallway, the subject goes to the loggia to smoke a cigarette. After that, he goes to the bedroom to turn on the light, and then back to the hallway to turn of the light there.
In terms of automated recognition of such patterns, it is important to note that neither the order of the events nor the exact composition of events is precisely defined. For instance, the other subject may turn on the light in the hallway, or the light might still be on, thus no motion in the hallway would be detected.
To test whether this pattern can be found in the data, we chose data of the evening times of 35 consecutive days. First, all data from sensors and actuators not involved in this pattern is removed. Second, using information on the placement of sensors, sequences of activity of neighboring sensors are detected.
Of the 35 days, the sequence was found on 28 days. The time of occurrence of the sequence is shown in Figure 7. The time of occurrence falls between 21:47 and 22:46 each day.

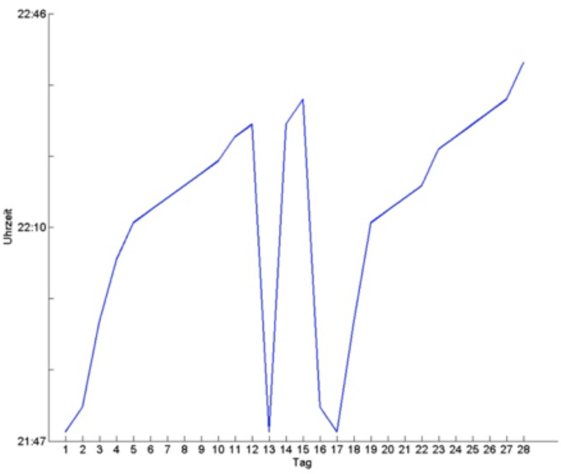

Abbildung 6: Determining frequently repeated rituals.

6 Disscussion

Although the project is still in an early stage, and further data analysis is necessary, it could be shown that certain behavior patterns, such as gait speed and presence by room, can be derived from the data. Furthermore, it is possible to find complex recurring behavior patterns with minimal effort.
The next step in the development of the system will be the deduction of automatable actions, i.e. finding patterns of behavior that can be executed by the LivingCare system automatically. For example, in the process of going to bed, the system might turn of lights and devices as subjects are leaving the room. To gain broad acceptance in a mass market, the detection of such patterns and actions must work reliably, thus particular effort must be made to implement these features error-free.
Lastly, the reinforcement algorithms will help to understand if certain automation steps are desired. Besides the obvious technical difficulties, home automation still requires the users' acceptance: while automation of rituals may be perceived as facilitation, some behavior patterns may be personally valuable to the user, or be supportive in maintaining physical and mental health.
To implement all aspects of the system, much work still needs to be done in regard to hardware and software development.

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