Pilot experiences on independent living in high age via non-invasive multisensory data analytics

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Abstract— **This work describes the self-management support experience of the Patients with Dementia (PwD) at home by delivering a technology integrated model of assistance to the Informal Caregivers (ICs). Based on the conducted pilot tests the authors analyse, if non-invasive sensing technologies, are able to support the assistance management of the ICs, by delivering reliable information about deviations on usual behavioural patterns of PwD. The work presents the basic results of using Recurrent Neural Networks (RNN) in behaviour classification and anomaly detection at home.**

Keywords—human device interaction, independent living, non-invasive sensing, activities of daily living, patients with dementia

I. Introduction

This paper aims to contribute to the field of ambient intelligence considering the real environments [1, 2], where noise levels in data are often significant [3], by showing how machine learning techniques can contribute to the knowledge creation, by promoting software sensors. The created knowledge can be actionable to develop features helping to deal with problems related to minimally labelled datasets. A case study is presented and analysed, looking to infer high-level rules, which can help to anticipate abnormal activities, and potential benefits of the integration of these technologies are discussed in this context. This work also aims to analyse the usage of the models for the knowledge transfer if different sensors with different settings contribute to the noise levels. Finally, based on the authors' experience, a framework proposal for creating aggregated knowledge is depicted.

Part of the difficulties and stress related to caregiving might be prevented by new Information and Communication Technologies (ICT) and by developing innovative support services for these people. This is very much in line with the current EU strategy on long-term care. For example, Horizon Europe program covers various clusters and partnerships, with specific attention to improving care quality and accessibility through technological innovations. The focus here is on increasing the resilience of health and care systems across the EU, particularly through the use of new technologies and innovations for supporting independent living of older people.

Recent study shows that dementia is among the most burdensome disease for the global society [4]. This study have the potential to inform regional and national policy makers, allowing the introduction of innovative and cost-effective interventions in order to reduce the burden of dementia on public finances and single families.

A. Overall objective 1:

The first objective of our work was to promote the use of Technologies to support the self-management of the Patient with Dementia (PwD) at home by delivering a technology integrated model of assistance to the informal caregivers.

B. Overall objective 2:

The second objective was to improve the state-of-the-art of behaviour classification and anomaly detection algorithms, consisting of two subobjectives:

Subobjective 1: Analyse, if non-invasive sensing technologies, are able to support the assistance management of the informal caregivers, by delivering reliable information about deviations on usual behavioural patterns of PwD.

Subobjective 2: Analyse novel machine-learning approaches like Recurrent Neural Networks (RNN) for the use in behaviour classification and anomaly detection.

II. Platform description

The technological Home4Dem system consists of:

- Home monitoring kit
- Remote server
- Care giver app
- Dementia literacy web
- Home4Dem Entertainment and Training Coach

A. Home monitoring kit:

The core of the technological platform is the home monitoring kit, consisting of a control unit and a set of ambient sensors such as passive infrared (PIR), smoke, water-leakage, and door contacts. An additional bed occupancy sensor was used which provides information about sleep pattern and physiological parameters such as heart-rate and respiration. All sensors (apart from the bed occupancy sensor) use a proprietary wireless communication protocol in the 868MHz range providing a coverage of 100m (indoors). The sensors are optimized for low-power consumption and can operate at least for 12 months. The bed occupancy sensor is powered by a wall-plug and communicates via GSM-router to a remote server. The control unit transmits all sensor data to a remote server via GSM-router or via wireless connection.

B. Remote server:

The server processes the data with two main aims:

- Detect dangerous situations
- Analyse the behaviour of the person to detect changes in the behavioural patterns

C. Caregiver app:

The Home4Dem caregiver's application displays the following information: (a) alarms and notifications depending on the severity of the events in the home, and (b) aggregated and analysed data describing the behaviour of the person and changes in the behavioural patterns. The caregiver can use these data to decide upon necessary interventions, be it immediate help in case of emergency, or just reminders to activate and entertain the person.

D. Dementia literacy resource:

The Home4Dem Dementia literacy resource provides clear information to caregivers to improve the understanding of the disease and its management, thus improving the literacy related to Alzheimer dementia. It provides a rapid access to contents related to:

- Basic information on the disease (educational programme)
- Instructions on how to deal with the patients in challenging situations
- Instructions on how to monitor the caregivers' quality of life and health status
- Whenever possible, information on basic local services in favour of informal caregiving.

E. Home4Dem Entertainment and Training Coach:

The Home4Dem platform also includes a mobile app based on already existing and commercially available service called Memas and includes entertainment services like web radio channels, preferred newspapers, photo albums, reminder service and a set of simple exercises to train the memory that the person with dementia can do on his/her own.

III. Platform functionality and setup

Due to the user's profile, the interaction between the technological platform and the caregiver will be limited only to a few operations, such as the possibility to activate / deactivate some functions. In order to achieve this, only few buttons will be available on the control unit, with simple led lights to indicate the state of the control functions.

The home monitoring system was designed to be minimally invasive. Shape and colour was chosen to allow the system to blend into the apartment. All sensors use double-sided tape and can be installed without drilling holes, making the installation and removal quick and easy. The participants (the persons with dementia and their caregivers) are particularly vulnerable and technological devices can be disturbing. For this reason, whenever possible, the sensor and the control unit were hidden. All the components used had CE certification or had undergone all the tests required by law.

In case of possibly dangerous situations, the system notifies the caregiver via the interface on its mobile app. The home monitoring kit addresses the following dangerous situations:

- in a moment of disorientation, the patient might run away from home and get lost (magnetic contacts must be placed on critical doors, presence sensors will try to detect if the PwD is still in the house or not)
- the patient leaves a water tap open and floods the room (water sensors must be placed in critical places)
- the patient cooks something on the stove, forgets it and causes a fire (smoke detection sensors must be placed in the critical places)
- the patient gets out of bed during the night and doesn't come back within a certain time interval (bed occupancy sensor and configurable time control). To lower the risk of fall, the system can turn on a light.

As one of the goals of this study was to verify the reduction in caregiver burden through the use of technology, it was critical to secure the activity of the platform during the field trial. In order to do this, all of the sensor signalling and control unit elaborations must be logged to an SD/RAM memory and sent to the server. Log information has registered the usage.

IV. Methods

A. Study design and expected outcomes

The study has been conducted as a case series (uncontrolled longitudinal study), where the observations were made on a series of enrolled individuals, receiving the intervention described below with no control group with data collected before and after the installation and use of the Home4Dem technical solution. Throughout the field trial, the users have been monitored through periodic structured interviews regarding the degree of usability, acceptance and satisfaction with the technical solutions [5]. The end-users have been recruited from the Neurology Unit and Alzheimer Assessment Unit (Memory Clinic) of the IRCCS INRCA.

Data has been collected in four different moments: during the recruitment phase, at baseline, one month after the installation and at the end of the test period after six months.

Primary outcomes of the field trial are:

- Reduction/stability of the informal caregiver burden, measured using the Zarit Burden Interview
- Improvement/stability of the informal caregivers' quality of life measured using the EQ-5D-5L scale

Secondary outcomes of the study are:

- Improvement/stability of the quality of life of the PwD measured using the EQ-5D-5L scale
- System acceptability by the PwD and the informal caregivers measured by Technology Acceptance Questionnaire, based on the Unified Theory of Acceptance and Use of Technology (UTAUT)
- Usability of the system by the informal caregivers measured using the System Usability Scale (SUS)
- System usability by the PwD according to the SUS

B. Protocols

30 dyads, formed by a person with mild cognitive impairment and his/her informal caregiver, have been selected based on stages of dementia. The inclusion criteria did not discriminate older people with other illnesses and/or disabilities, in order to reach a sample which is reflecting the real characteristics of the end-users population.

Inclusion criteria:

1. The recruited subject should be informal caregiver of a person with cognitive impairment or dementia in stage 2-4 on the Global Deterioration Scales (GDS) (Reisberg et al 1982) equals 19-29 points on Mini Mental State Examination (MMSE), (Palmquist et al. 2012);
2. The cared person should be:
   a) aged ≥ 65;
   b) with Instrumental Activities of Daily Living (IADL) (Lawton & Brody, 1969) score ≥ 5;
   c) living in ordinary housing; and informal caregivers cohabiting or living close by.

Exclusion criteria:

1. Lack of informed consent from caregiver or the person with dementia (PwD);
2. Presence of severe diseases associated with life expectancy less than 6 months, in addition to dementia, or unstable chronic conditions, in either the dementia patient or the family caregiver, self-reported by the patient or the informal caregiver or by a specialized clinician;
3. Intention to move to institutionalized care.

C. Data collection

Recruitment phase:

The recruitment protocol has included general information on the subjects, in particular, health status and cognitive condition. The information has been collected with the help of the caregiver / family member. The recruitment protocol has included include: IADL, GDS and MMSE.

Baseline:

Before the start of each Home4Dem field trial, the selected participants have been invited to a pre-testing session, named Baseline evaluation, which has consisted of the first real contact with the users and their families. This visit was preliminary to the installation of the technological kit.

First evaluation

The aim of this data collection was to analyse the usability and acceptability of the system, after a short period of use. The evaluation of the system usability has been conducted by adopting qualitative and quantitative techniques.

Final evaluation

The aim of this phase was to collect useful information on the whole benefits perceived by the users after a meaningful period of use of the system. The final evaluation has been conducted after the system de-installation, in order to detect and analyse the impact of the system in the daily life of the older people and their family and to gain knowledge on elderly technology acceptance and usability issues and provide methodological approach for further studies in the field.

D. Behaviour Change detection

To detect changes in behavior patterns, we have implemented an algorithm based on activity-curves proposed by Dawadi [6]. This algorithm first aggregates activity distribution of small time-windows to "activity curves" that span a whole day.

An activity distribution models the daily routines as a probability distribution over a set of activities in a specific period. This distribution is estimated based on the normalized time an individual spends on a predefined set of *n* activities during the time interval *t*. An activity distribution for time interval *t* is an *n*-element set $\boldsymbol{D_t} = \{d_{t,1}, d_{t,2}, \cdots, d_{t,n}\}$ of *n* probabilities for each activity in the activity set $\boldsymbol{A}$. An activity curve C is simply the compilation of activity distributions $\boldsymbol{D_t}$ ordered by time interval *t*.

Besides the simple "activity curve" which models the curse of daily routines over one day, one can aggregate such a curve over a specific time-window of *x* days. This aggregated activity curve is a compilation of *m* aggregated activity distributions, which are the maximum likelihood estimate of the mean for *x* activity distributions.

If $\Sigma = \{C_1, C_2, C_3, \cdots, C_x\}$ is a set of activity curves of *x* days and a single aggregated activity distribution $\widehat{\boldsymbol{D}}_{\boldsymbol{t}}$ at time interval t is calculated as:

$$\widehat{\boldsymbol{D}}_{\boldsymbol{t}} = \sum_{k=1}^{x} \frac{\boldsymbol{D}_{k,t}}{x} \quad (1)$$

Then, an aggregated activity curve can be written as: $C^{\Sigma} = \{\widehat{D}_1, \widehat{D}_2, \widehat{D}_3, \cdots, \widehat{D}_m\}$

Changes in behavior are detected by comparing activity curves at different time-points. This comparison is in turn based on a permutation-based two-sample tests to determine whether there is a significant change among a set of activity distributions at a particular time interval. The symmetric Kullback–Leibler divergence is used as a simple distance metric to compare each individual activity distribution.

V. Results

A. Sample description

The Italian sample was composed of 25 dyads. Sons and daughters were the principal caregivers in a fairly large percentage (88%), while brothers / sisters were the caregivers for the 8%. In only one case (4%) the caregiver was the spouse / partner. The description of the participants is reported in the next paragraphs.

B. PwD description

The PwDs were 17 women and 8 men, with mean age of 80.8 (SD= ±6.25). A large percentage were widowed (68%), almost one-thirds were married (28%) and only the 4% were divorced. The majority has a primary level of education (80%), followed by the secondary (20%).

Most of the participants were retired (92%) while the 8% refused to answer. The income sources were represented by pension (88%) and help from relatives (4%), however the 8% of the sample refused to answer. Almost half of the sample

(48%) declared to live with only one person (24% spouse or partner; 8% son or daughter; 4% brother or sister; 12% paid caregiver). Another significant percentage (44%) reported to live alone while only the 8% of the sample answered to live with two people.

The average IADL score is 2.28 (SD=±2.22), meaning a low level of autonomy in using daily tools for daily life, while the average score of MMSE was 17.77 (SD=±4.59), in line with the Persona profile defined in the Home4Dem project.

According to the Reisberg scale the sample reflected the following percentage of cognitive decline: moderate 48%; moderately severe 44% and severe 8%. Finally, referring to the Health status, the mean score of EQ-5D VAS scale is 69.2 (SD=± 28.81), suggesting a good self-perception of the quality of life.

The expectations regarding the Home4Dem system aspects in the Table 1, were asked to be rated by the PwDs using a 5-point Likert scale from 1= Not at all to 5= All the time.

Table 1. Ratings of Home4Dem system expectations by PwDs

Item	Mean	SD
I'm confident to use the system and its features	2.07	1.07
I have the capabilities and stamina to use the system without discomfort, stress and fatigue	2.00	1.17
The supports, assistance and accommodations exist for successful use of this device	4.57	0.86
I will feel comfortable using the system around family	4.14	1.16
I will feel comfortable using the system around friends	4.07	1.32
I will feel comfortable using the system in community	4.07	1.32
The system will benefit and improve my quality of life	3.35	1.49
The system will help to achieve my goals	3.35	1.49
The system will physically fit in all desired environments	3.78	1.05
I will feel more secure when using the system	3.71	1.26
The system will fit well with my accustomed routine	4.14	0.86

The result at the ATDPA shows an overall positive attitude towards technology (M=39.28; SD=±7.90). Only two items reported a lower average (mean <2,07). In particular, the PwDs recognized benefits in the use of technology in the daily life (improvement in quality of life, achievement of goals, perception of security). However, a significant part of PwD (44%) doesn't know how to answer the questions.

C. Informal Caregivers description

The sample of informal caregivers (IC) was composed by 16 women and 9 men, with aged 55.12 years old on average (SD=±7.47). According to the results, a large percentage is married (64%), while 12% of participants are divorced or single. In addition, the 8% of the caregivers is engaged in a full time relationship and only the 4% is widowed. Regarding the education, the majority of the IC reached a secondary level of education (72%), followed by the tertiary (24%) and the primary (4%).

The working situation of the sample is also described: most of the participants are still working full time (76%), while the others are retired (20%) or work at home (4%). The main income source is represented by work (76%) and pension (20%). A minority of the sample refused to answer (4%).

About one-third of the sample (32%) declares to live with only one person (20% spouse or partner; 4% son or daughter; 8% mother or father). Most of the respondents (44%) answered to live with two people while a little percentage (8%) lived with three people. In addition, the 8% of the sample reported to live with four people, however the 8% lived alone.

About the social network, the 32% of the sample seems to be at risk of social isolation at the LSNS-6.

The expectations regarding the Home4Dem system aspects in the Table 2, were asked to be rated by the ICs using a 5-point Likert scale from 1= Not at all to 5= All the time.

Table 2. Ratings of Home4Dem system expectations by ICs

Item	Mean	SD
I'm confident to use the system and its features	4.04	1.13
I have the capabilities and stamina to use the system without discomfort, stress and fatigue	4.60	0.76
The supports, assistance and accommodations exist for successful use of this device	5.00	0.00
I will feel comfortable using the system around family	4.68	0.85
I will feel comfortable using the system around friends	4.66	0.86
I will feel comfortable using the system in community	4.60	0.91
The system will benefit and improve my quality of life	3.64	1.22
The system will help them to achieve my goals	3.68	1.06
The system will physically fit in all desired environments	4.36	0.86
I will feel more secure when using the system	4.04	1.13
The system will fit well with my accustomed routine	3.44	1.38

The majority of the results shows a positive attitude towards technology (M=47.12; SD=±5.91). In particular, the informal caregivers expressed to recognize benefits in the use of technology in the daily life and to feel comfortable to use the system in different environments. In addition, respondents are confident about technology and they trust in Home4Dem system in terms of perceived safety, but most of all, they reported to feel confident about using the system with no additional stress of fatigue.

Regarding the Caregiver Burden, a minority of the sample (20%) is comprised in little or no burden range. However, a fairly large percentage of participants (40%) reached a mild to moderate range.

On the other hand, a moderate to severe range is represented by the 36% of caregivers while only the 4% obtained severe burden range.

Finally, referring to the Health status, the mean score of EQ-5D VAS scale is 66.6 (SD=± 17.89), suggesting a good self-perception of the quality of life.

D. Technical results

The data from 48 apartments was analyzed (Switzerland = 4, Norway = 9, Sweden = 10, Italy = 25) of which (8.3%) were unusable for further analysis due to severe data errors. 28 of the 44 remaining apartments (58.3%) were marked as unreliable because of individual sensors failures or larger gaps where no or erroneous data could be collected. The remaining 16 apartments (33.3%) were without significant sensor defects. Table 3 summarizes the data quality in all apartments.

Table 3. Data quality over all pilot apartments

Country	Apartments	Unusable	Unreliable	Ok
Switzerland	4	0	1	3
Norway	9	1	3	5
Sweden	10	2	7	1
Italy	25	1	17	7
Total	48	4	28	16

Median recording duration of all apartments (including unusable and unreliable) was 187.5 days.

Table 4. Recording duration over all pilot apartments

Country	Mean [d]	Min [d]	Max [d]
Switzerland	83.0	42	117
Norway	269.2	125	547
Sweden	185.6	57	255
Italy	166	65	304

Case-Study-1: Apartment 17163746-i

This apartment shows a high degree of regularity and structure. Each day starts at 08:00 AM with toileting events followed by living-room and out-of-home events till 01:00 PM. Afterwards, there is a brief period of bedroom events followed by living-room events. From the activity patterns of the outdoor events, we can assume that this person is employed and works 5 days a week for about 3-4hours. The Figure 1 shows the change-score for a time-window of 15 mins and a window-size of 7 days. Due to the small window-size, even small deviation from the initial behaviour distributions contribute to an increase in the change-score. The calculated change-score increased to about 0.18 and stayed constant during the whole measurement period.

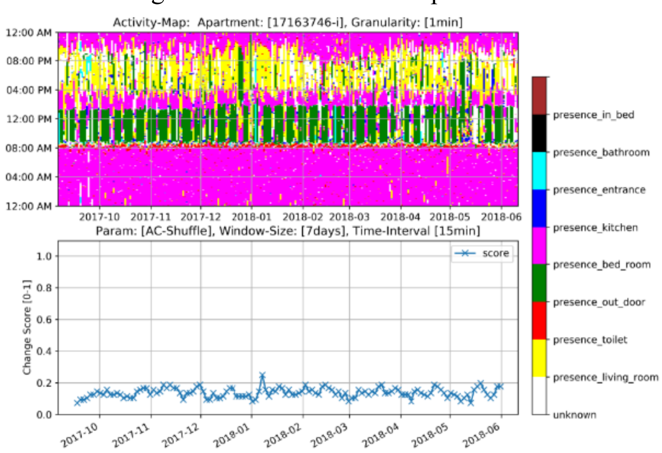

Fig. 1. Apt 17163746-i, window size: 7 days, time interval: 15 mins

Increasing the window-size to 14-days (time-interval = 60 mins) captures a broader sample of typical behaviour patterns which and has a better chance to reflect normality in behaviours. Similar to the increase in the time-interval, the increase in the window-size has a smoothing effect. The change-score exhibits a reduced sensitivity for small variation but is able to better capture slow changes in time. For example, on the Figure 2 we start to see a significant increase in change-score between February and March 2018. During this period, the subject went to bed much earlier than usual, which can be seen in the activity-map at 08:00 PM for the aforementioned period.

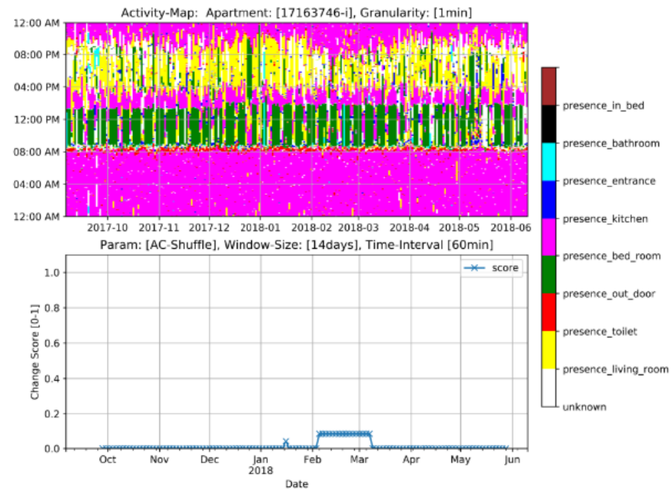

Fig. 2. Apt 17163746-i, window size: 14 days, time interval: 60 mins

Case-Study-2: Apartment h4d-ita-5

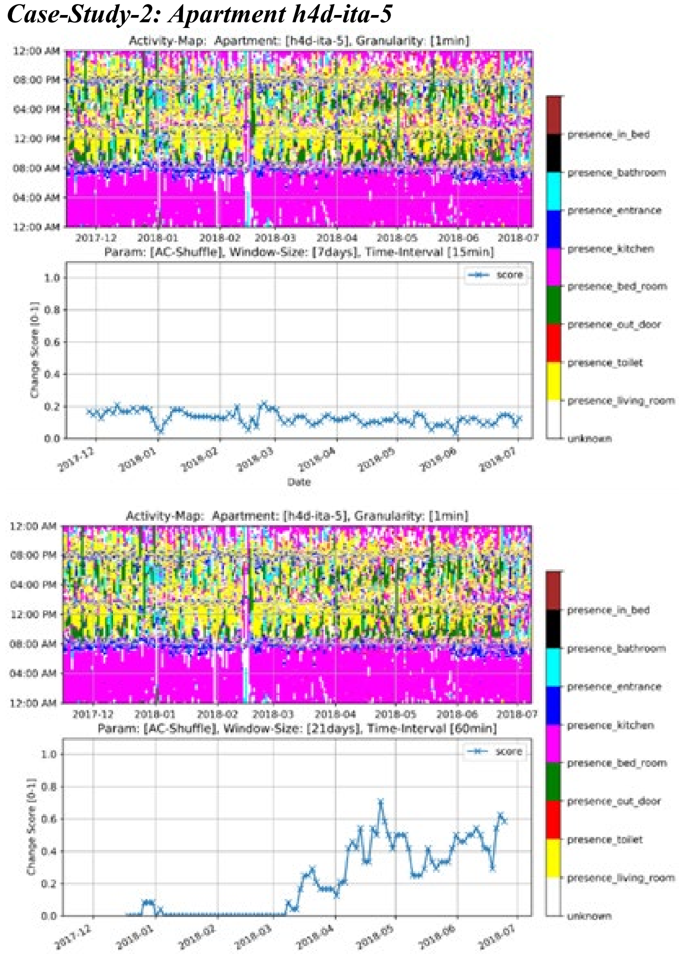

Fig. 3. Apt h4d-ita-5, window size: 7 / 14 days, time interval: 15 / 60 mins

In contrast to apartment 17163746-i, h4d-ita-5 shows a higher degree of irregularity. Each day starts at about 07:00-

07:30 AM with kitchen events, followed by events in the living room or outdoors. From the inspection of the activity-map, there is only a slight shift in the daily activities visible during the period from June to July 2018 where the day start has shifted from 07:30 to 07:00. Other changes can't easily be identified. The reference window for change-score calculation was also set to the beginning of the measurement period.

Similar to 17163746-i, Figure 3 (top left) shows a static change-score of about 0.18-0.20 for a time-interval of 15 min and a window size of 7 days. Increasing the window-size to 14 days (time interval=15min) reduces the static change score about 0.05. Simultaneous increase in time-interval to 60min brings the change-score for the first half of the measurement period to almost 0. This indicates that the typical activity patterns are captured well. During the second half of the measurement period there is a steady increase in change score visible. This change could be attributed to a malfunction of the presence sensor in the bathroom where for the first half of the measurement period, no data could be collected.

VI. Discussion

The methodology for evaluating and detecting changes is a challenge for further research. In this work, the data quality was too bad for in-depth evaluations. Missing data was one of the biggest problems, encountered during the preprocessing and analysis phases. The three main reasons for missing data are: placement errors, low sensitivity, and transmission errors.

Placement errors occur when PIR sensors were installed at inadequate locations. In an ideal case, each room is equipped with a dedicated PIR-Sensor, which only detects movement in its particular room. Due to the big field of view, inadequate placement of the sensors leads to cross-detection. This is the case where a sensor detects movement in adjacent rooms.

Low sensitivity is another challenge, faced when analyzing the data. Low sensitivity means, that not all movements of a person were detected. Elderly people often move slower than younger people which constitutes an additional challenge for the PIR-Sensor design. Also, PIR-Sensors do not measure temperature directly but measure differences in thermal radiation (far Infrared). To enable detection of human movement, the sensors are equipped with a specialized optics with divides the field of view into segments / zones of interest. A person moving from one zone to another generates a temperature differential that can be measured. Higher Zone-Counts improves the sensitivity to small movements, but requires a higher temperature difference between the object and its surroundings. High ambient temperatures also reduce the sensitivity to movements because of the reduction of the temperature difference of a person to its background.

The third challenge are transmission errors and some data losses occurring because of wireless transmission technology.

However, more sensors could help. Apart from the transmission errors and data failures in the Home4Dem project, we have never been able to examine the actual quality of the recorded data in more detail because a.) We no longer had time for data analysis in the project and b.) We had no access to the ground-truth data (MMSE scores). With other algorithms, we might be able to find out a lot from the data, even if we could not find any significant changes with our chosen approach.

VII. Conclusion and Outlook

Future improvements should consider the opportunity of being adaptable to smart objects as for example small social robot, also to provide games oriented to memory support using stimuli of emotional salience, as for example autobiographical memories. On the technical side, it turned out that even though many sensor systems are available on the market, it is not self-evident that these systems can prevent data loss. Further investigations are needed in this area to guarantee stability. However, once the data is collected, data quality is sufficient to get deep insights into the daily behaviors of the Person with Dementia. Formal and informal caregivers successfully used these findings for a better understanding of daily routines.

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