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Evaluation of a Radio Based ADL Interaction Recognition System in a Day Hospital for Old Age Psychiatry with Healthy Probands

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Abstract— **In this contribution the evaluation of a system called "Eventlogger" is presented, which is installed in a day hospital for old age psychiatry. The Eventlogger is a radio based module with an adjustable communication range, able to recognize interaction of the user with objects or with other people. It is intended to function as a monitoring tool for the users' activities. Due to the demographic change monitoring systems for elderly people become more important. In this paper the "simple activities of daily living" (sADL) is introduced as well as the evaluation for the recognition of sADL in a day hospital for old age psychiatry with healthy probands is presented. Together with the first approaches of post processing for better results it is shown that the system is now ready to be used with patients of the day hospital for old age psychiatry.**

I. Introduction

Germany and other developed countries are facing more and more healthcare challenges. Through the continuously rising life expectancy and the low birth rate the number of elderly people is increasing while the younger age group is decreasing. The demographic change is accompanied by a large increase in geriatric and gerontopsychatric disorders, particularly dementia.

Currently dementia affects 5% of all people above 65 and over 40% of people over 90 years [1]. Dementia, a chronic disease in most cases, is characterised by a cognitive decline as well as disturbances of emotional control, social behaviour, or motivation [2]. Typically, the deterioration of cognitive impairment goes along with an inability to perform the personal activities of daily living.

An examination of a patient with dementia includes psychometric testing as well as an assessment of the activities of daily living. For this purpose, two specific sets of activities have been defined [3]. One describes the basic Activities of Daily Living (bADL) and focuses on the functional status of a person and includes personal hygiene, using the toilet, bathing/showering, eating, etc. The other one, the Instrumental Activities of Daily Living (IADL), describes interaction with the physical and social environment. A variety of standardized interviews are available i.e. Barthel Index [4] which defines for example the activity "getting on and off toilet" as autonomous when: "*Patient is able to get on and off 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*."[5]. The assessment of the ADLs is crucial for an early diagnosis of dementia. Furthermore, monitoring ADLs throughout the disease allows an estimation of disease progression. Last but not least, the ability to perform ADLs is one of the most important outcome parameters in clinical trials. An objective, automated assessment of patients' performance of ADLs would be desirable. An automated tool could give information about self maintenance abilities and even slight changes of the activity profile.

Unfortunately all the activities mentioned in the Barthel Index are too complicated to monitor in the first step. Therefore a "simple ADL" (sADL) is introduced. The sADL is interpreted out of an interaction with an object (e.g. Toilet), so when the patient is near the toilet it is assumed that the sADL "toileting" is fulfilled correctly. In this paper an approach is suggested, based on a device presented in [6], [7] and [8] that allows detecting such sADL. For evaluation, the system was installed in a day hospital for old age psychiatry, tested with healthy probands and compared with written minutes. In this paper the possibilities of post processing are also discussed to achieve even better results.

II. State of the Art

As already mentioned the Barthel Index (BI) is a widely used ADL-scale to test the autonomy of elderly people [4]. The data is collected by asking questions about the ability to autonomously carry out daily routines. All these data finally amount to a score which reveals the severity of ability dysfunctions. The questionnaire is filled out either by a nurse or, if possible, by the patient.

The major disadvantage of these questionnaires is their subjectivity. Ranhoff et al. [9] assert that the scores attained by doctors through interviewing the patients directly were insignificant. Another study [10] was made to investigate whether different sources of data (patient, nursing staff, relatives, doctor) lead to the same score. It turned out that patients usually overestimate their functional activities whereas external observers mostly underestimate them. A further disadvantage of ADL-scales is that they are

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implemented when the person is already in care. Thus it is impossible to detect a slow process of degeneration of everyday activities at an early stage. It is generally known that early detection increases the chance of a slower degradation process as well as reducing the health care costs [11].

In research, there are various projects with the aim of developing a system that is able to detect different ADLs automatically. They are based on different technical systems. To begin with infrared systems, based on PIR-sensors (Presence Infrared Sensors) [12][13], oversee certain areas of interest and detect movements. Then video based systems like [14] monitor certain small areas and detect different activities within. Furthermore approaches have been done by video systems combined with switches [15][16] as well as combined with RFID systems [17][18][19]. Apart from that multitude of research is based on RFID. [20][21] for example, integrated a RFID reader first into a glove and later on into a bracelet. Also [22] made and evaluated a mobile RFID-reader. M. Stikic et al. [23][24], tried to increase the amount of information about the activities by adding an accelerometer. Each technology has its own advantages and disadvantages.

The disadvantage of the PIR-sensors is that they cannot distinguish between different users or between humans and pets. Video based systems have problems with occlusions and also the acceptability is in dispute. By adding other systems to the video based systems, some disadvantages can be solved, but the complexity of the data is getting higher. Yet RFID-readers for mobile applications have only a reading range of about 10cm which follows out of the miniaturisation. This range most of the time is not enough to detect activities of people.

III. MATERIALS AND METHODS

Based on a scaleable local communication like the IR-modules in [25], the hardware of the systems consist of radio modules which was already described in [7] and [8] that are broadcasting their IDs (ID_n) twice a second (f_T = 2 Hz). The time needed for transmitting ID_n d_T is 1 ms. The communication range r_{ADLn} of the radio modules can be set to a value from 0.3 metres to 40 metres. This was done by adjusting the transmission power $TP(ID_n)$. It could be set in 64 steps and covered the following range of values:

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

If there have been two modules with the positions in the same room:

$$p_{ID_n}\begin{pmatrix} x_n \\ y_n \\ z_n \end{pmatrix} \text{ and } p_{ID_m}\begin{pmatrix} x_m \\ y_m \\ z_m \end{pmatrix} \quad (2)$$

ID_n will detect ID_m when they are closer together then the communication range $r_{ADL\,m}$:

$$\left| p_{ID_n} - p_{ID_m} \right| \le r_{ADL_m} \quad (3)$$

And so an event E(t) is defined as:

$$E_m(t) = \begin{cases} 1 & \Leftrightarrow \quad \left| p^T_{ID_n} - p^T_{ID_m} \right| \le r_{ADL_m} \\ 0 & \quad \text{else} \end{cases} \quad (4)$$

As the modules check $E_m(t)$ with a receiving frequency of f_R = 0.5Hz and a receiving duration d_R = 501ms, the saved sADL were $sADL_n[k]$ with the specific time [k]:=k($1/f_R$). For an easy interpretation as well as saving storage and energy only the sADL together with the starting time and the duration were saved at the end. To clarify this process the detection of one event is shown in Fig. 1 and described in the following.

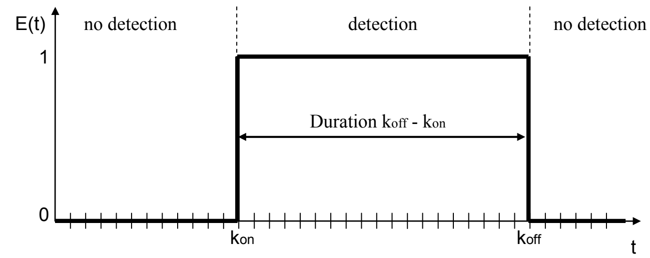

Fig 1. Detection of an event to save a sADL with the start time kon and the end time koff.

In the first step the edges of ID_n were analysed. With a rising edge the variable F_n [k] becomes one, with a falling edge F_n [k] it becomes zero. When ID_n has not changed, then F_n [k] is not defined:

$$F_n[k] = \begin{cases} 1 & \Leftrightarrow \quad E_m[k\text{-}1] = 0 \wedge E_m[k] = 1 \\ 0 & \Leftrightarrow \quad E_m[k\text{-}1] = 1 \wedge E_m[k] = 0 \\ n.d. & \quad else \end{cases} \quad (5)$$

When F_n [k] was one, the starting time k_{on} was saved. When F_n [k] was zero again, the $sADL_n[k]$ was created, consisting of the ID_n, the start time k_{on} and the duration $k_{off} - k_{on}$:

$$\text{if } F_n[k] = ON \Rightarrow k_{on} \quad (6)$$

$$\text{if } F_n[k] = OFF \Rightarrow sADL_n[k] := [ID_n, k_{on}, k_{off} - k_{on}] \quad (7)$$

The data was saved in the module ID_1 as follows:

$$\begin{pmatrix} sADL_n[k]_1 \\ \vdots \\ sADL_n[k]_m \end{pmatrix} = \begin{pmatrix} [ID_{n1}, k_{on,1}, k_{off,1} - k_{on,1}] \\ \vdots \\ [ID_{nm}, k_{on,m}, k_{off,m} - k_{on,m}] \end{pmatrix} \quad (8)$$

The memory was read out wireless via a base station to a computer. The computer visualized and analyzed the recorded data.

For detailed information about the modules communication range initialization as well as the detailed hardware design please refer to [7].

IV. Evaluation

To get first datasets from elderly people, the system was installed in a day hospital for old age psychiatry. At the beginning of the practical study a pretest with non patients to evaluate the setting was done. This test run will be evaluated and discussed in the following.

A. Experiment Setup

The system was installed in a day hospital for old age psychiatry for elderly people of the Klinikum Rechts der Isar, Munich. Together with the staff of the day hospital the following objects/rooms were equipped with an Eventlogger:

- Kitchen/dining area
- conference room
- nurses' room
- men's toilet and men's basin
- women's toilet and women's basin
- two times the entrance (one indoor, one outdoor)
- the occupational therapy room and the PC in this room
- the physiotherapy room

The floor diagram in Fig. 2 shows most of the objects/rooms with the according communication range of each Eventlogger.

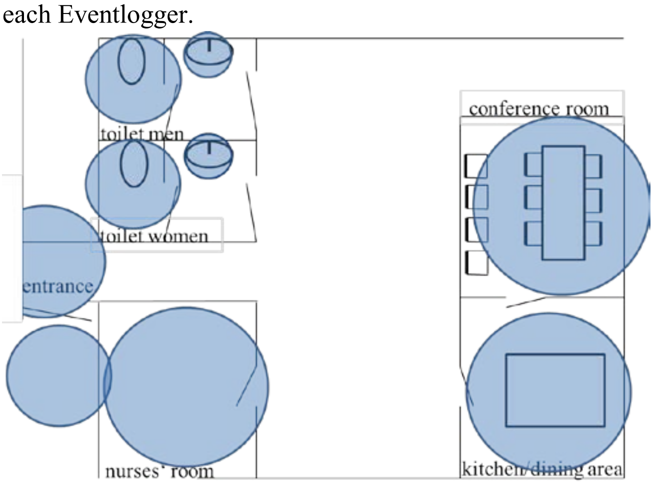

Fig. 2. Floor diagram of the upper floor of the hospital with the communication ranges of the different Eventlogger

Within this setup it was expected to be able to track the important actions of the patients in the hospital. To extend the Eventloggers lifetime up to one month they were put into boxes with a battery pack. For practical reasons it was decided, that the Eventlogger should be worn on a wristband. After setting up the range of each Eventlogger the test run started with ten voluntary healthy probands. Five subjects wore the wristbands with the Eventloggers for three hours while each of the other five probands took the minutes of one of the subjects. Therefore, ten voluntary non-patients were needed. To not disturb the normal daily routine in the day hospital the test was made on a weekend, when the day hospital is usually closed. After the experiment the worn Eventlogger were read out using the base station and the data was saved in a SQL-database (ME, measured sADL). To compare the data with the data recorded form the minute takers they were also put into the SQL-Database (RE, recorded sADL). For the evaluation two different methods were used:

1) Performance in short sADL detection

Every recorded event is set as one, e.g. going through the entrance or washing the hands:

$$RE\langle i\rangle\left[ID_n, k_{on}, k_{off}-k_{on}\right] \qquad \Rightarrow RE\langle i\rangle = 1 \tag{9}$$

If there is at least one measured event in the same timeslot ±10s ME is also one, else zero:

$$ME\langle i\rangle \in \left[k_{on}-10s,\dots,k_{off}+10s\right] \;\Rightarrow ME\langle i\rangle = 1 \tag{10}$$

$$ME\langle i\rangle \notin \left[k_{on}-10s,\dots,k_{off}+10s\right] \;\Rightarrow ME\langle i\rangle = 0 \tag{11}$$

Results to the sensitivity Sens1:

$$\frac{\sum_{i=1}^{i=N_{ME}} ME < i >}{\sum_{i=1}^{i=N_{RE}} RE < i >} = Sens1 \tag{12}$$

The corresponding measured events ME in (9) are searched within 10 seconds before and after the recorded sADL because obviously the minute takers were not able to write down the sADL time to the split second. The specificity 1 is not calculated, as the "right negative" can only be calculated if it is divided into timeslots. This would result to the same like specificity Spec2.

2) Performance in long sADL detection

e.g. sitting in the kitchen or in the conference room:

with the sensitivity Sens2 which is all durations summarized from measured events within the recorded events divided through the duration of the recorded events:

$$D_1 = \left\{ i \in \mathbb{N} \;\middle|\; ME\langle i\rangle\left[k_{off}-k_{on}\right] \in RE, 1 \le i \le N_{ME} \right\}$$

$$\frac{\sum_{i \in D_1} ME\langle i\rangle\left[k_{off}-k_{on}\right]}{\sum_{i=1}^{i=N_{RE}} RE\langle i\rangle\left[k_{off}-k_{on}\right]} = Sens2 \tag{13}$$

as well as the specificity Spec2 which is the total time minus all durations summarized from measured events outside the recorded events divided through the time of non-recorded events:

$$D_2 = \left\{ i \in \mathbb{N} \;\middle|\; ME\langle i\rangle\left[k_{off}-k_{on}\right] \notin RE, 1 \le i \le N_{ME} \right\}$$

$$\frac{totaltime - \sum_{i=1}^{i=N_{RE}} RE\langle i\rangle\left[k_{off}-k_{on}\right] - \sum_{i \in D_1} ME\langle i\rangle\left[k_{off}-k_{on}\right]}{totaltime - \sum_{i=1}^{i=N_{RE}} RE\langle i\rangle\left[k_{off}-k_{on}\right]} = Spec2 \tag{14}$$

B. Results

1) Performance in short sADL detection

The evaluation result according to (11) gives a total Sens1 of 80.3%. The detailed numbers of measured sADL and recorded sADL are shown in Table I.

TABLE I
NUMBER OF MEASURED SADL VS. RECORDED SADL (EVENTS)

Eventlogger	$\sum_{i=1}^{i=N_{RE}} ME<i>$	$\sum_{i=1}^{i=N_{RE}} RE<i>$	Sens1
Kitchen (dining)	34	36	0,944
conference room (sitting)	10	11	0,909
nurses' room (demand)	0	12	0,000
toileting (men)	2	2	1,000
hand washing (men)	2	2	1,000
toileting (women)	4	6	0,667
hand washing (women)	6	7	0,857
entrance (outdoor, leaving)	5	8	0,625
entrance (indoor)	25	32	0,781
occupational therapy room	20	21	0,952
pc occupational therapy	4	5	0,800
physiotherapy room	10	10	1,000
total	**122**	**152**	**0,803**

Unlike in the other rooms, where the Eventlogger sent out their ID within the whole room, the Eventlogger inside the nurses' room was set to send out its ID near the door. The range was adjusted much too low, which may explain why the nurses' room was not detected at all. The two Eventloggers for the entrance were installed on the left and on the right side. Throughout the experiment at least one of the Eventloggers were detected, but sometimes the second was shielded by the body of the person or the minute taker. The higher detecting rate from entrance (indoor) compared to entrance (outdoor) arises from the building setup. To reach the occupational therapy room and the physiotherapy room people had to go downstairs and to pass by close to the entrance (indoor). These findings clarify that it is important to install the Eventlogger in an adequate place. Especially for detecting short events (like going through a door) it is recommended to take two Eventloggers and place one on each side.

2) Performance in long sADL detection

The total Sens2 was 72.7%, while Spec2 was at 99.4%. The missing percent for Sens2 were mostly because of the conference room. Here the test subjects were sitting in chairs in the room's corners so that they were not detected properly (see Fig.2). The communication range was set up for "sitting around the big table", so people sitting in the chairs were mostly out of range. This setup was changed after the test run by setting a higher communication range. In addition to this the minutes were sometimes shifted to the measured data, which might also indicate mistakes of the minute takers. However, for this evaluation the minutes are considered as 100% correct.

The logged events had gaps of some seconds to some minutes, which might be because of occlusions or similar effects. As the specificity of the system is quite high it was tested whether there are better results with the following definition, which ignores gaps smaller then x:

$$\text{if } k_{on}\left(ME\langle i\rangle\right)-k_{off}\left(ME\langle i-1\rangle\right)\le x;$$
$$x\in\left[30s;60s;120s;...\right] \quad (15)$$
$$\Rightarrow k_{on}\left(ME\langle i\rangle\right)=k_{off}\left(ME\langle i-1\rangle\right)$$

The results are displayed in Fig. 3:

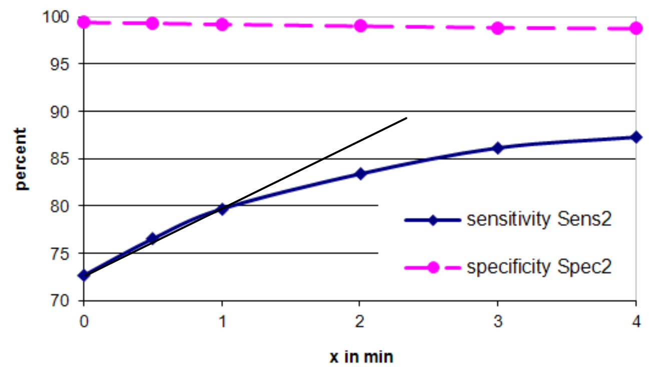

Fig. 3. Sensitivity and specificity compared with different filled gaps of duration x

By filling gaps smaller than one minute Sens2 got 79.7% which is already 6% better than the first result. The Spec2 decreased only by 0.2%. After one minute the Sens2 gradient was getting lower. That is why in the next evaluations in the day hospital for old age psychiatry, gaps smaller than 60 seconds will not be considered.

C. Discussion

The results of the evaluation proved that the system is working in the day hospital for old age psychiatry and can be used for analyzing patients. The setting of the communication range still needs further development as sometimes it is set to small. The problem of shielding by bodies at short events might be solved by adding a second Eventlogger on the other side, as shown at the entrance. One of the biggest challenges will be the small gaps that sometimes occur. Further experiments have to be done in order to gain better knowledge about them. But so far better results can be achieved by "filling gaps smaller than one minute". This could be done because it is unlikely that the same task is done twice within one minute. By adding more rules, e.g. "not filling the gap when other contacts are made within the same time", better results could be attained.

With the sensitivities Sens1 and Sens2 as well as the specificity Spec2 quite good results were reached. It is suggested that, changing the communication range of the nurses' room and adding another Eventlogger in the entrance as well as considering the slower moving of elderly people, will reach a sensitivity Sens1 of about 90%.

V. CONCLUSION

In this article the evaluation of the system Eventlogger for the detection of interaction with objects was presented. The system was installed in a day hospital for old age psychiatry. Within the experimental setting it was shown that a sensitivity of 80% with a weighting of short events detection and also a sensitivity of about 73% with a weighting of long events detection was achieved. Adding the rule that gaps of less than one minute are ignored, the sensitivity of nearly 80% with a weighting of long events detection could be reached. With this test run the first step towards the development of an automated tool is made.

With these promising results the Eventlogger will assess patients' activities of daily living in the day hospital for old age psychiatry in a next step. The whole experiment will be supervised by a clinician to show the usability of the system for non developers.

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