Challenges and Possibilities in Observational Lifestyle Monitoring Technology for the Elderly: A Scoping Review

Bachelor's Thesis

by

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Abstract

Background: Given the rising number of elderly people in society that one day will outweigh the possibilities of health care institutions, alternative solutions have to be found to offer a safe but independent lifestyle to the elderly. Ambient assisted living (AAL) systems serve this function by monitoring elderly people in their own homes. The recorded data can be accessed by pre-defined caregivers, both formal and informal. In case of unusual data that are alarming in regard to the resident's health, this group of caregivers probably can react faster than they could without the data of the system. This literature review aims at giving an overview of unobtrusive AAL systems designed for providing more safety for the elderly in their own homes. The resulting overall research question is: What are possibilities and limitations in observational lifestyle of the elderly? This question was answered by giving answers to the following sub-questions: What objectives do the monitoring systems pursue and how are they operationalised? What is the reliability and validity of the different technology methods? How are the data of the monitoring systems stored and who can access them?

Methods: Based on several inclusion and exclusion criteria it was searched for suitable papers in the database Scopus. Among the inclusion criteria were the use of only privacy-preserving sensors and the use of sensors that did not need to be constantly worn on the body. Papers that were not written in English, did not include monitoring systems with the aim of assisting the elderly but another population and studies that included privacy-threatening technologies were not included in this literature review.

Results: Seven eligible studies were found. The systems described in these studies were compared in the prevalence and the operationalisation of AAL services as physical health tracking (including sleep pattern, vital signs, and body weight), mental health tracking (including cognition and well-being) and safety enhancement (including emergency detection and the possibility to call for help). Furthermore the quality of the system was assessed in terms of validity and reliability, data storage and data access. It was striking that in many studies clear numbers concerning reliability were missing, and also information on data access and storage was scarce. However, an overview of a variety of sensors used in monitoring systems is provided for physical health tracking and emergency detection. Mental health was not often taken into account in these systems.

Conclusion: In the future, more attention needs to be turned to usability concerns and to a more profound assessment of reliability and validity, sensitivity and specificity, study design and duration, and privacy concerns.

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1 Introduction

While worldwide the old population is growing, so does the need for appropriate care for the elderly (Bradford & Zhang, 2016). Prospectively, there will be more people over the age of 65 than there will be people under the age of 14 in the year of 2050 (WHO, 2012). Given the fact that already now many residential care facilities are short-staffed but at the same time crowded in terms of residents (Kayser-Jones, Schell, Lyons, Kris, Chan, & Beard, 2003), this high number of elderly persons will eventually outweigh the possibilities of formal care givers in nursing homes, and a shift to a greater reliance on informal caregivers is likely to be seen. Additionally, most elderly people wish to be cared for at their own personal home instead of a nursing home (Herrera-Tejedor, 2017; Uhlig & Bahrmann, 2014). Taking these factors together, the wish for staying in one's own house and the prospected insufficient number of places at nursing homes, the future elderly care at one's own home seems to be advantageous – and it indeed can be, but therefore it must be ensured that the quality of care does not decrease.

In order to reach this aim, several monitoring systems have been invented. Monitoring systems consist of sensors that are spread over the house, in different rooms and on objects, and that send their data to a server and/or to mobile devices as smart phones or tablets (Nap, Lukkien, & Cornelisse, 2016). These data inform a selected group of people as formal caregivers, doctors, and relatives, about the daily actions the resident is taking. By this, it gets possible for a pre-defined group of people to get information about which rooms the resident has been in, and whether particular objects have been used (e.g. microwave, wardrobe). However the monitoring is not restricted to movements in the house, there are also devices that measure physical processes in the resident as for example his or her blood pressure (e.g. Bradford, van Kasteren, Zhang, & Karunanithi, 2017). The aim of these monitoring systems is to detect any occurring changes in lifestyle habits and bodily functions. Subtle hints that are measured could not only make a faster reaction to emergencies (e.g. strokes) possible, but might also prevent them from occurring in the first place.

Those monitoring or ambient assisted living (AAL) systems have the ability to track, record, analyze and interpret data coming from sensors that represent the activity of elderly people (Kara, Lamouchi, & Ramdane-Cherif, 2017, p. 393). By doing so the systems shall support elderly persons who are still able to live independently but who are at risk of losing this independence. AAL can be defined as “electronic environments that are sensitive and responsive to the presence of people and that provide assistive propositions to help them maintain an independent lifestyle” (de Ruyter, Zwartkruis-Pelgrim, & Aarts, 2010, p.116). Especially three features of AAL systems are fundamentally important: sensing, communicating, and acting (Queirós, Silva, Alvarelhão, Pachecheco Rocha, & Teixeira, 2015). The different *sensors* measure activities and the resident’s state of being, they *communicate* with the other devices used in the system to make sense of the measured information, and this information forms the basis which the system *reacts* upon as an assistant for the resident.

Monitoring systems differ in how intrusive they are. Some make videos of the resident in order to get a clearer picture of his or her activities and state of health (e.g. Cucchiara, Prati, & Vezzani, 2007; Fleury, Noury, Vacher, 2013). While systems using cameras are somewhat more accurate in recognising activities than are systems relying solely on auditory sensors (94.99 % compared to 83.35 %) (De Silva, 2008), due to privacy issues and ethical concerns cameras are hardly used in healthcare monitoring systems (Caine, Rogers, & Fisk, 2005). Also devices that have to be worn on the body or need to be kept highly maintained are unpopular among the elderly (Bradford & Zhang, 2016). Even though the accuracy of data would theoretically be increased with these devices, the benefit is vanished if the residents refuse to use them

When speaking of privacy of the resident, another issue that needs to be taken into account is confidentiality. The different sensors used in the AAL systems collect a large amount of data of the resident. Especially those systems which aim at detecting unusual events (e.g. Aran, Sanchez-Cortes, Do, & Gatica-Perez, 2016) are in need of pre-recorded data to decide which behaviour patterns are far from usual. However, wearable sensors are often too small to have a high storage capacity and moreover, their battery supply is also highly limited (Li, Lou, & Ren, 2010). An additional issue is the data access. While having access to a patient’s data when needed could actually save him or her (Halperin et al., 2008), the permission to see the data should be given only to a selected group of people. Otherwise the patient might become a victim of malicious ambush (Li, Lou, & Ren, 2010). Therefore, caution needs to be taken here.

1.1 Examples of Sensor Types

Motion detectors serve as possibilities to detect any deviations from normal lifestyle habits. By recognising in which room the resident is at the moment, it could for instance be noticed by the care givers if the bathroom was not used for a long time. Passive infra-red sensors (PIR) are installed for tracking where in the house the resident is (Lotfi, Langensiepen, Mahmoud, & Akhlaghinia, 2012). Furthermore, motion detectors are not restricted to rooms. Also objects that are moved will be detected if they are endued with special motion sensors. Typical examples of this are door/window entry point sensors that can detect when the door of e.g. a microwave or the wardrobe gets opened (Lotfi, Langensiepen, Mahmoud, & Akhlaghinia, 2012). They belong to the category of binary sensors, thus they are only capable of measuring one of two conditions, in this case open versus closed (Amiribesheli, Benmansour, & Bouchachia, 2015). In order to interpret the measurements of these binary sensors correctly, a good understanding of the resident's habits is necessary. A clearer picture is given when many binary sensors are installed (Amiribesheli, Benmansour, & Bouchachia, 2015). Otherwise there is no guarantee that preferable actions as eating have been done, simply on the basis of an opened and then closed fridge door. Pressure detectors in the couch and bed show when and for how long the resident was sitting/lying (Lotfi, Langensiepen, Mahmoud, & Akhlaghinia, 2012). Again for a correct interpretation of data, the habits of the resident must be known, but if this knowledge about the resident is there, abnormal patterns can serve as an alarm signal.

1.2 Contribution of this Study

There is a great variety of AAL systems used for healthcare purposes. The growing number of elderly people makes it necessary to find systems that simplify informal and formal caregiving while also offering the greatest security possible for the resident without affecting his or her quality of life by being too intrusive. When taking the aforementioned negative impacts of cameras on the privacy of the resident into account it is understandable that the focus of this study lies on unobtrusive lifestyle monitoring systems. Unobtrusive in this case means that the use of sensors is restricted to measurements of movement, sounds, and vital functions, without the need of constantly wearing those sensors. The research question is: What are possibilities and limitations in observational lifestyle of the elderly? To get an answer to this question, the different AAL systems will be compared in terms of indicators of daily functioning of the elderly, the system's ability to adapt to the resident's behaviour, whether there are arrangements for checking on health and unusual events, and whether the system can get personalised. It is important to find out how reliably the observed behaviour patterns can be measured and who will have access to the information provided by the sensors. Thus, the following sub-questions result:

1) What objectives do the monitoring systems pursue and how are they operationalised?
2) What is the reliability and validity of the different technology methods?
3) How are the data of the monitoring systems stored and who can access them?

With this overview, opportunities and shortcomings of existing lifestyle monitoring programmes can be listed. Although there already are other literature reviews about AAL systems, this literature review is unique in the criteria and AAL services that were chosen as a basis on which to compare the systems. Thus, this review aims to raise the awareness for positive and negative aspects of these lifestyle monitoring systems in order to help finding convenient and sophisticated programmes but also to show facets of systems that have proven to be less beneficial. In the end, by having an overview of the current state of art the process of finding a highly suitable system for elderly people, or developing one, gets facilitated.

2 Method

Scoping reviews are made to give an overview of the already existing breadth of literature concerning a specific topic of interest (Brien, Lorenzetti, Lewis, Kennedy, & Ghali, 2010).

2.1 Search Strategy

For answering the aforementioned questions, several studies on in-home monitoring systems were compared. For finding these studies the following search terms were used:

<u>Set 1</u>: elderly, aged, old
<u>Set 2:</u> lifestyle monitoring, in-home monitoring, ambient assisted living, AAL
<u>Set 3:</u> system

These search terms were chosen because they were frequently used in studies that had been read before in order to become more familiar with the current state of research. Set 1 is about the target group of the AAL systems. Since this scoping review aims to provide information on existing monitoring systems for elderly persons, only those studies are taken into account that are about AAL systems suitable for aged people. Set 2 and 3 both concern the used technology. While it is self-speaking that some kind of *system* is searched for (Set 3), there are different names for these technologies, listed in Set 2. The general strategy was to search for papers that were published from 2009 on and had one word of set 1, set 2 and set 3 in their title, abstract or as a keyword in it. The database Scopus was used with the following search string:

(TITLE-ABS-KEY ((ambient AND assisted AND living OR aal OR lifestyle AND monitoring OR in-home) AND (elderly OR aged OR old) AND system) AND ACCESTYPE (OA) AND PUBYEAR > 2008

Several exclusion criteria have been chosen. Studies that make use of privacy-threatening cameras in their monitoring system were not taken into account because of the aforementioned practical and ethical concerns in regard to cameras. Also papers that cannot be accessed fully were excluded. No other language than English was taken into account. Studies using monitoring systems that were made with the aim of increasing physical activity were excluded as well. The resulting criteria the studies needed to fulfill are testing lifestyle monitoring systems that could be used for detecting changes in lifestyle habits and/or bodily functions of elderly persons, who live at their own home (instead of nursing homes).

Table 1: Inclusion and Exclusion Criteria of Studies

Inclusion Criteria	**Exclusion Criteria**
Full text available	Full text not available
Target group; suitable for aged people, thus > 69 years of age	Target group: aimed solely at young people
Sensors: non-wearable sensors included	Sensors: solely wearable sensors, privacy-threatening cameras
Objective: monitoring lifestyle, detecting changes and emergencies	Objective: solely aiming at increasing physical activity
Language: English	Language: other than English

The studies found by the use of this method were screened for eligibility by reading the titles and, if still applicable, the abstracts. If by reading the abstract a study did not seem to fulfill the criteria of this literature review, the particular study was not included. However, if in the abstract no reason for exclusion was seen, the study was read further. This procedure was repeated with the remaining articles as well, until all suitable papers were identified. These studies were read carefully and the information of particular interest for this review was written down both in text and table form.

2.2 Data extraction

The information that has been taken from the resulting studies can be divided into three clusters: The first group of data that were extracted from the studies was an overview of the context in which the studies were conducted. Basic information about the research was written down, including:

Authors:	names of the authors
Year:	year of publication
Country:	country of the study
Setting:	setting of the study: either solely in a lab or additionally at a real home (real-life assessment)
Study Design:	how the study was designed
Duration:	time frame in which the testing of the system was done
N:	number of participants
Study Population:	basic information about participants, i.e. age and health state

The second group of extracted information concerns the core of the system, namely objectives the system pursues, and the allocation of operationalisation possibilities of these features. Based on the literature that was read to get an overview of the state-of-the-art concerning AAL systems, several features were identified that were present in several monitoring systems and therefore seemed to play an important part. These features/services are:

Physical Health Tracking

Vital Signs:	ability to keep track of the resident’s vital signs (temperature, pulse, blood pressure…)
Sleep:	ability to keep track of the resident’s sleep pattern (i.e. at what time he/she goes to sleep, at what time he/she gets up, how many times he/she leaves the bed during the night

Weight: ability of keeping track of the resident's body weight

Mental Health Tracking

Cognition: possibility to keep track of the resident's cognitive skills

Well-Being: tracking of the resident's mood, subjective health state ranking, emotions

Safety Enhancement

Detecting Emergencies: recognising dangerous incidences based on e.g. untypical location of the resident or anomalous behaviour as falling

Arrangements to Call for Help: integrated features that make a call for help possible

The third table concerns the quality of the systems. Therefore, in this cluster, information was extracted that would help to assess the AAL systems in terms of the pre-determined points of interest (see sub research questions): validity and reliability of the systems, data storage, and data access. The assessment of how data are stored and who could access them were found to be quite subjective and should better be left to the future users themselves, because preferences may vary here. While some residents and their family might see the advantages of data stored in a cloud that is accessible by all relevant caregivers without any restrictions, others might want to keep their health data stored safely in a local place, or want to give different caregivers access to only a pre-defined type of information, etc. However, a ranking in terms of the reliability/validity of the systems was done. Systems making use of sensors that had a measurement accuracy of >80 % were labelled with "++" (ElHady & Provost, 2018). Systems using sensors with a measurement accuracy ranging from 60 % to 80 % were labeled with "+". "-" is the label of all sensors with a low measurement accuracy. Low quality in this case means a measurement accuracy below 60 % or a description in words that gave grounded suspicion that the reliability and validity of the sensors was not satisfying. If in a study information about validity or reliability was missing, this would be made visible with the "N.A." label in the ranking table.

3 Results

The aforementioned search string resulted in 50 studies in Scopus. Based on their title, nine studies were excluded because they already made clear that the systems described in the studies aimed at another population. Another 22 articles were excluded based on their abstract for reasons that can be found in Figure 1. N=15 papers were excluded based on their full-text because it turned out that they aimed at increasing physical exercise or made use of privacy threatening sensors. Eventually, four eligible studies have been found in Scopus. Based on a recommendation a fifth article was included. Two more studies were found by going through the reference lists of already included studies. Thus, in total seven studies have been selected.

Although based on the search string an inclusion of studies published after the year of 2009 was possible, the oldest study actually included was published in 2010, and more than half of the studies were published after 2012. Except for one Australian study [5], all studies were conducted in Europe.

As can be seen in Table 2, the seven studies almost all were assessed under real-life conditions [2, 3, 5, 6, 7] and two were assessed solely in a lab with the help of actors as a surrogate for real users [1, 4]. Those were simulation studies. Of the five studies that were assessed in real homes all were observational studies in which no allocation to different groups and conditions was done. The whole study population tested the AAL system at home and apart from the differences in houses or flats no other differences were intended. The duration of the study is not mentioned in three of the papers [1; 4; 7]. The duration of the remaining studies ranges from 2 weeks [3] to 16 months [6].

The number of participants varies highly. While there is one study not providing information on the size of the population, the population sizes of the remaining studies range from 2 [3] to 189 persons [7]. The age of the elderly persons in the pilot studies does not differ strongly, though. While in one study it is only spoken of “elderly persons” without giving the exact age [6], the participants in the other studies had a mean age of around 84 years of age [2; 3; 5], except for one study in which the participants had a quite young average age of 74 years [7].

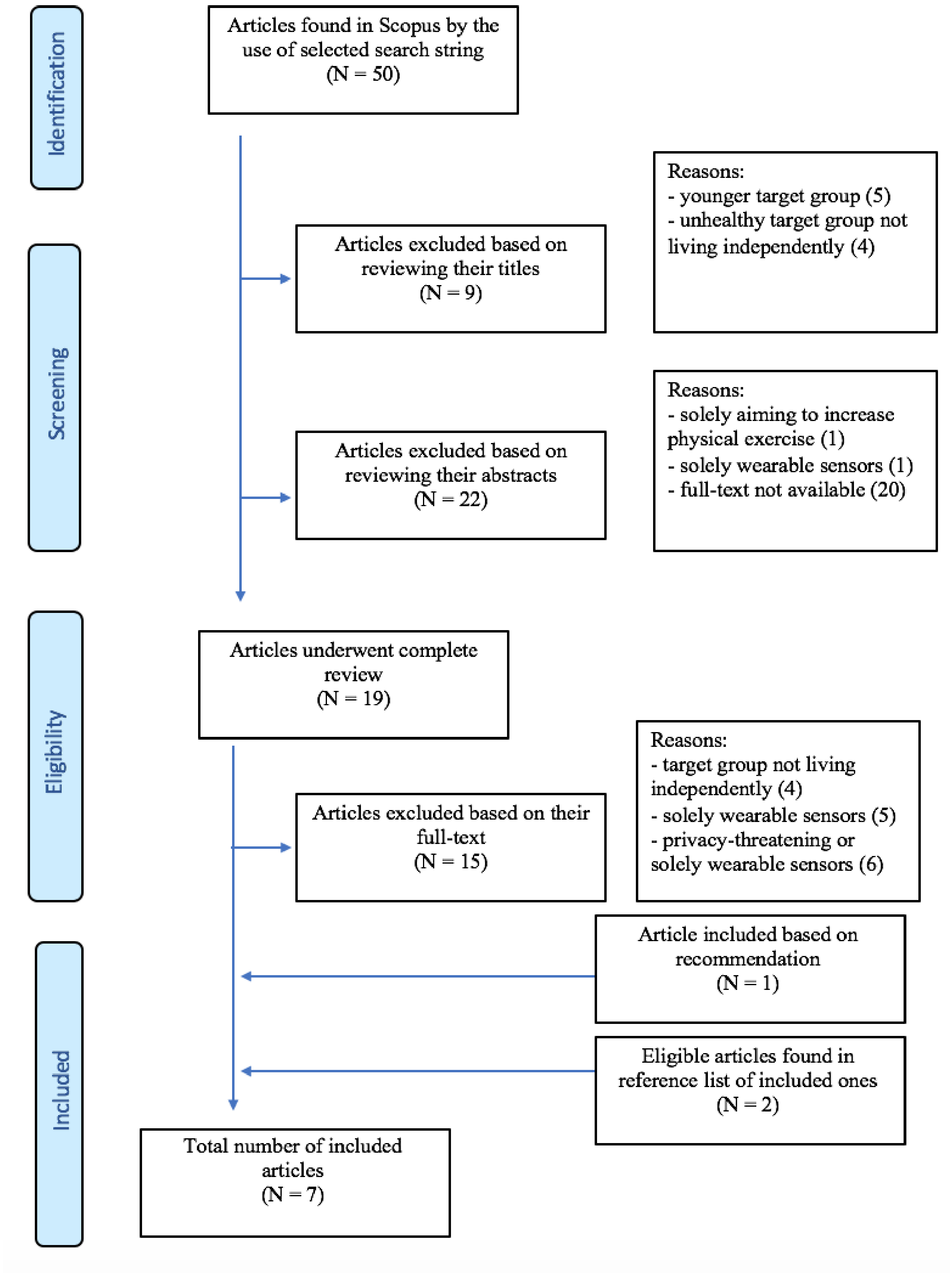

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flowchart.

Table 2: Overview of Included Studies

Number	Authors	Year	Country	Setting	Study Design	Duration	N	Study Population
1	Leone, Diraco, & Siciliano	2013	Italy	lab real-home	simulation study	N/A	10	- no real users, only actors - around 31 years old - healthy
2	Aran, Sanchez-Cortes, Do, & Gatica-Perez	2016	Switzerland	lab real-home	observational study	4 months	40	- minimum age 62, maximum age 96 - average age: 84,3 - 28 subjects declared to receive help from family (based on questionnaire)
3	Dadlani, Sinitsyn, Fontijn, & Markopoulos	2010	The Netherlands	lab real-home	observational study	2 weeks	2	- average age: 83 years
4	Villacorta, Jiménez, del Val, Izquierdo	2011	Spain	lab	simulation study	N/A	N/A	- no real users, only actors
5	Bradford & Zhang	2016	Australia	lab real-home	observational study	12 months	6	- 79 to 87 years of age - average age: 84 - no dementia
6	Botia, Villa, & Palma	2012	Spain	lab real-home	observational study	16 months	25	- elderly persons
7	Bierhoff et al.	2013	The Netherlands, Spain, UK	lab real-home	observational study	N/A	189	- average age: 74 years - 31% indicated no age-related problems (based on questionnaire) - others reported for example declining physical health/mobility, forgetfulness, and financial difficulties

3.1 Objectives of the Systems and their Operationalisation

RQ1: What objectives do the monitoring systems pursue and how are they operationalised?

Physical Health Tracking

Regarding the objective of "Physical Health Tracking", the AAL service of keeping track of the resident's vital signs was found in N=2 of the seven systems [4; 5]. This rather infrequent usage of devices that monitor such fundamentally important health condition could be due to the decision that in this literature review only unobtrusive AAL systems were included, thus no system that made use of sensors that needed to be worn permanently. Both systems [4; 5] involve medical devices to keep track of vital signs. In the adapted surveillance system [4] portable devices are mentioned that are integrated in the AAL system in order to measure temperature, heart rate and similar crucial physical signs. The description suggests that no particular devices had been chosen yet. However, the intention to do so was made clear, when the system would actually be used by elderly persons. Temperature is also measured in the study conducted by Bradford and Zhang [5] but instead of the heart rate it was chosen to additionally measure blood pressure. While data of the blood pressure are automatically uploaded to the system, the temperature data need to be typed in manually.

N=4 systems [1; 3; 6; 7] keep track of sleeping patterns. In the study of Bierhoff et al. [7] a bed occupancy sensor located above the bed recognises when the elderly gets up. N=2 studies [3; 6] make use of pressure sensors that are installed under the bed. By this they recognise when the person is lying in bed. The objective of these sensors is to observe the person's sleeping pattern (based on the time spent in bed and the frequency of getting up at night).While in these three systems the recognition of sleeping is dependent on the resident's presence in bed, in the study conducted by Leone, Diraco, & Siciliano [1], the activity of sleeping is recognised based on the exact body posture. This is done by 3D sensors. One characteristic of these sensors is the accurate measurement of exact body posture in a way that is usually only reached with the help of cameras. However, in contrast to camera pictures, the graphics built out of the 3D sensor data form just a representation of a human-being instead of clear videos. Privacy invasion is therefore kept to a minimum. This study [1] is the first to make use of these innovative sensors in an AAL system. The monitoring system is equipped with a large class of key postures it can identify. These are further divided into four levels: the first level are the four basic postures of bending, standing, sitting and lying down. The second level takes the elderly's centroid height into account, always measuring the distance to the floor plane at the same time. This is for distinguishing lying down on the sofa and lying down on the ground. The third level is about the position of the body's torso, and the fourth level about the positon of the body's extremities. Based on this sophisticated technology, the sensors can recognise different activities, among them the activity of sleeping.

Despite the different sleep detecting sensors used in these four systems, it has to be noted that the measurement stays superficial. None of the sensors is able to measure sleep quality.

The third AAL service, related to the tracking of physical health, is the measuring of the elderly's body weight. This is done in N=2 studies [3; 5]. In the so-called Aurama system [3] the same load sensors are used for weight measurement as for sleep tracking: the aforementioned pressure sensors under the bed measure the additional weight that is laid down on the bed. In contrast to the system described by Bradford and Zhang [5] in which the resident needs to step on a weight scale to keep track of his/her weight, the weighing in the Aurama system [3] is done automatically during the elderly's presence in bed.

Mental Health Tracking

N=4 systems [1; 3; 4; 7] provide technologies that are related to the cognitive skills of the user, however, the intentions vary here. Two of the systems keep track of the elderly's cognitive state: the Aurama system [3] contains computer games that assess cognitive skills. The elderly needs to solve riddles like the mental rotation task (imagining to rotate a three-dimensional object in order to compare it to another one and find out whether they are the same). The elderly's progress on these games is stored so any changes (both improvements and declines) are made visible in the user's profile. In the study conducted by Leone et al. [1] again the described 3D sensors are used to keep track of the elderly's health. However, unlike the games in the Aurama system, the 3D sensors monitor the elderly's cognition state without him or her necessarily being aware of that. In the same way the 3D sensors aim to recognise activities like sleeping and exercising, they are constructed to detect if the elderly is in the "wandering state". This is one of the behaviours dementia patients show: wandering describes the activity of walking around disorientedly. Although this literature review aims to provide an overview of systems that could be used for independently living elderlies instead of dementia patients in particular, this service can be of advantage for the alleged healthy elderlies as well because it may help in detecting signs for serious cognitive diseases as dementia.

While the 3D system [1] and the Aurama system [3] are concerned with passively monitoring the elderly's cognition, the other two systems that provide AAL services related to cognition actively intervene [4; 7]. They do so by sending reminders of taking one's medicine (if required). While in the study of Villacorta et al. [4] nothing more about the reminders is said than that they will appear on an extra display module, in the SOPRANO system [7] the medication reminding service is described as this: there is a particular point in time set when the elderly gets a reminder of his or her medication. The medication dispenser is technically programmed so it gets recognised whether the dispenser was opened or not. If no action from the resident is taken several other reminders get sent until (after a pre-defined period of time) a message is sent to the caregivers. The reminders included in these two systems [4; 7] therefore serve as an intervention with relation to cognition. Although the reminding of taking medication can enhance both *physical* and *mental* health (depending on the purpose of the medication) it moreover has an informative value concerning the cognitive abilities of the elderly and was therefore allocated to AAL services related to cognition: if regularly several reminders are necessary before the elderly takes his/her medicine this could be a hint on declining cognitive abilities while in the case of a regular intake of medicine with almost no reminder needed for it, no decline in memory performance could be noticed.

The feature allocated to the tracking of mental health was the monitoring of well-being. Of all the AAL services that were described in this review, the monitoring of well-being is the one that is least frequently included in the systems: only in N=1 study [5] this feature is mentioned. The monitoring system includes a digital diary in which the resident can describe his/her subjective state of being, in terms of mood, feelings, mental and physical health.

It is striking that compared to the physical health tracking, mental health tracking is an infrequently set goal in the described monitoring systems. While some aspect of physical health gets measured in almost all of the systems [1; 3; 4; 5; 6; 7], a real *assessment* of a variety of cognitive skills is only seen in N=1 study, namely the Aurama system [3] in which cognition is tested with games. The other three studies that relate to cognition [1; 4; 7] do not make use of any assessment measures of cognitive abilities in general but are limited to one single element of cognition as being in danger of wandering [1] or regularly forgetting to take one's medicine [4; 7]. Getting a broad picture of the cognitive state is not possible with these features. Subjective well-being is included in the studies even more scarcely, given that only one study [5] includes it while it does not play any role in the remaining six systems.

Safety Enhancement

Except for the Aurama system [3] all the compared AAL systems included at least one possibility to detect or report emergencies. A sent alarm based on untypical locations that were defined before could be seen in more than half of the systems [2; 4; 5; 6]. Two of these systems [5; 6] base their definition of anomaly of the location on the time the person spends in a particular room: Dependent on the resident's typical behaviour, the amount of time until an alarm is sent differs per location. For example, a stay in the bedroom for 8 hours should not raise concerns, however an 8-hour stay in the kitchen definitely should. Although this is likely to hold true for every elderly, the exact duration of staying in the same room without the need for an alarm differs per person. The AAL system described by Botia et al. [6] additionally takes different days of the week into account. Thus, an exceptionally long stay in a particular room that occurs on a regular basis (e.g. taking a longer nap than one does on other days of the week, after a walk through the park every Tuesday) won't cause an alarm either.

In the monitoring system of Aran et al. [2] not the duration of the stay but the time of the day is important. In this system a behaviour model is created based on the components of time of the day and resident's location. If the location of the resident at a given point in time is different from the previously recognised behaviour pattern this is noticed as an anomaly (e.g. the resident normally gets up at 9 am but now still lies in bed although it's 11 am already).

Villacorta et al. [4] add a third way to detect anomalies that is based solely on the location of the resident (thus, duration or time of day are not taken into account). In this monitoring system information about normal movements/actions of the resident get stored. For example, if the stored information about the resident is that she needs to lie in bed all day, a movement at another location in the house would cause an alarm, however this would not be the case for a resident who is said to walk around the whole house independently. This can be a helpful feature even for quite healthy independently living people (which this literature review is about) because they could suffer periods of illness. So if the elderly person does not feel well for a few days and it is important that she rests in bed, the settings in the tailored profile could be changed so caregivers in this case do get an alarm when the resident is not resting anymore. The tracking of the resident's location in these systems is done by pressure sensors [2; 6], motion sensors [2; 5; 6], acoustic sensors [4], and door sensors [2; 6].

Probably because of the high risk of falling as an elderly, a fall detection option was very frequently integrated [1; 4; 5; 6; 7]. However, one unique additional feature was seen in the SOPRANO system which was developed in a human-centered approach [7]: After the detection of the fall the system asks the resident whether everything's OK. In case of no reassurance an alert message is sent. Again it is remarkable that none of the other systems included this question for reassurance because falling does not necessarily mean that the resident is actually in need of help.

Nevertheless, three systems include the autonomous decision of the resident in another way: the possibility to call for help by him- or herself. In N=2 systems [4; 5] panic buttons are installed in several places in the house in hopes that the resident can reach them whenever help is needed. Also the SOPRANO system [7] makes use of such a button but it is not made clear whether it needs to be worn on the body or is installed at a particular place in the house.

No emergency arrangements could be found in the Aurama system [3]. This monitoring system is more concerned with long-term changes that might raise suspicion. Alarm messages get sent when unusual changes in, for example, the sleeping pattern occur. However, no arrangements are implemented for the case of an acute emergency.

Table 3: Objectives of the Systems and their Operationalisation

	Physical Health Tracking			Mental Health Tracking		Safety Enhancement	
	Vital Signs	Sleeping Patterns	Weight	Cognition	Well-Being	Detecting Emergencies	Arrangements to Call for Help
1	N.A.	3D sensors	N.A.	3D sensors (recognising wandering state)	N.A.	fall detector	N.A.
2	N.A.	N.A.	N.A.	N.A.	N.A.	location sensor (pre-defined alert conditions)	N.A.
3	N.A.	pressure sensor	pressure sensor	computer games (assessing cognitive ability)	N.A.	N.A.	N.A.
4	medical devices	N.A.	N.A.	reminders	N.A.	-fall detector -location sensors (pre-defined alert-conditions)	panic buttons
5	-blood pressure monitor -thermometer	N.A.	weight scale	N.A.	diary	-fall detector -location sensors (pre-defined alert conditions)	panic buttons
6	N.A.	pressure sensor	N.A.	N.A.	N.A.	-fall detector -location sensors (pre-defined alert conditions)	N.A.
7	N.A.	radar above bed	N.A.	reminders	N.A.	fall detector	security red button

3.2 Reliability and Validity of the Systems

RQ2: What is the reliability and validity of the different technology methods?

No clear numbers for validity and/or reliability were given in more than half of the studies [3; 4; 5; 7]. However, all the systems were tested at least in the lab, most of them additionally in real homes, and although clear numbers are not given in many of the systems, all the studies evaluate the system's reliability at least in words.

The 3D sensor system and the so-called Necesity system [1; 6] were found to have the highest reliability/validity of the seven systems and were labelled with "++" based on their measurement accuracy of above 80% (see 2.2 Data extraction). The Necesity system [6] detects 100 % of the falls in the lab, with *false* alarms occurring in the real-life setting one time in three out of nine houses over the course of one month (while the other 6 houses are free of false alarms). Unfortunately, no true positive rate (TPR) is given for detecting falls in the real home environment. The 3D system [1] recognises 83 % of the falls in real houses correctly as falls, with a true negative rate (TNR) of 97,5 %. Other features of this system that get evaluated in real-life are the recognition of wandering (TNR: 92.7 %, TPR: 81.6 %) and the detection and categorisation of activities of daily living (TNR: 98.3 % and TPR: 96.4%). In the lab, additionally the service of the recognition of body postures gets evaluated. A dataset consisting of more than 6,800 postures has been generated for this purpose. In a lab it was tested how accurately the different key body postures could be classified. As mentioned before, the postures were divided into four levels: the first level are the four basic postures of bending, standing, sitting and lying down. These were correctly identified in 84% of the cases. The second level takes the elderly's centroid height into account, always measuring the distance to the floor plane at the same time. This was done with an accuracy of 83%. The third level (the position of the body's torso) was correctly measured in 82%, and the fourth level (positon of the body's extremities) in 83% of the cases. Despite the good rating in terms of reliability, the 3D sensor system [1] has the major disadvantage that by now no solution could be found to the problem that no more than one person can be present in the house for the system to run smoothly.

This problem is tried to be tackled in the study by Villacorta et al. [4] in which every visitor is given a special bracelet that can be read by an RFID reader in the room. However, in the testing of the system it turned out that these readers could not reliably distinguish between the different identities. It was suggested that more readers would be needed for that. No clear numbers are given, though. The lack of statistical numbers that makes a justified labelling of the system's reliability/validity impossible is also seen in the study conducted by Bradford & Zhang [5]. Although both systems [4; 5] are described as being reliable systems, this does not provide enough evidence to label them with a "+" in this review.

The lowest ranking in reliability/validity was seen in [3; 7]. The system called Aurama [3] was tested for two weeks on two families, each consisting of one child and one parent. There were several difficulties in regard to validity shown in the test trials. The load sensors under the bed did not measure the weight of the person correctly because in some cases, several pillows were removed from the bed before going to sleep. Hence, the weight of the bed was below zero before the person lay down. Another problem concerning the load sensor was that only *presence* in bed is measured. However, this does not say much about actual sleeping patterns. One parent for example used to read for a long time in bed before sleeping. However, based on the location, the data on the tablet counts this as sleeping time as well. Just like the Aurama system [3], no clear numbers are provided for the SOPRANO system [7] either, however it is literally described as an unstable system with frequent crashes. Therefore, its reliability is ranked with a "-".

A decent reliability was found in the behaviour model system [2]. Concerning the accuracy of location measurement, the data measured by the sensors were compared to the actual information on location written down in a journal by the participant. In 64% of the cases the sensors were correct about the person's location inside the house. Concerning anomaly detection, an hourly measurement was conducted taking both location and time of the day into account. The true positive rate for this was 0.66 and its *false* positive rate 0.29.

Thus, five of the seven systems were described to be of good quality concerning reliability and validity [1; 2; 4; 5; 6]. However, in only three of these five studies this statement was supported by numbers [1; 2; 6].

3.3 Data Storage and Data Access

RQ3: How are the data of the monitoring systems stored and who can access them?

Information about where the data get stored and who could access them was one of the most differently handled things in the studies. In half of the studies [1, 2, 6, 7] nothing about data storage and its access was said. Those studies focused on the development of the system, an explanation of the sensors and/or the reliability of their functions. However, in the remaining studies the data were stored either solely online [5] or additionally in a database that can get accessed from a computer that's operating in the same network [4] or the data are stored solely on a server that regularly sends updates to carers [3].

For example, the data of [5] can be seen on different websites (called "portals") for different people. The family portal is accessible for family members, however, the resident decides him/herself which family member gets access to which information. This means that the residents have the possibility to differentiate between their caregivers in terms of the kind of information the system shares with them. This provides the user with more privacy and a greater part in the decision-making process, thus more independence in general. The clinical portal is used by clinicians. Both portals, the family and the clinical one, can be accessed with a URL from any computer, thus no special device is needed. Also the resident him/herself can view their own data on the tablet they were provided with at the beginning of the study.

The Aurama system [3] is highly concerned with building a connection between the residents and their family members. The resident's data stored on a server sends visual health information to the family every minute. The data are received by tablet PC of a family member. This tablet PC looks like a digital photo frame with a glowing edge of the screen. Depending on the state of the elderly person this edge of the screen changes its colour, e.g. yellow indicates unusual sleeping patterns, while blue means that the elderly is at home. However, not only family members have a tablet PC but also the elderly person him- or herself. They can see their own health data on it.

It stands out that while the Aurama system [3] is all about connecting family members, even allocating different colours to different health states to see at first sight what's going on, half of the studies do not answer the data access question at all. And even the studies that provide information on data storage and access do not make clear to what extent the data are protected from malicious attacks, and how easily accessible they are for the pre-defined group. For example, is a log-in to the portal/website necessary to receive alarm messages?

Table 4: Reliability/Validity of the Systems, Storage of the Resident's Data and Access to the Resident's Data

	Reliability/Validity in Lab	Reliability/Validity at Home	Reliability/ Validity Label	Data Storage	Data Access
1	**activity recognition accuracy:** 1st level: 84% 2nd level: 83% 3rd level: 82% 4th level: 83%	**fall detection**: TNR[2]: 97.5% TPR[3]: 83% **wandering state:** TNR: 92.7% TPR: 81.6% **activities of daily living:** TNR: 98.3% TPR: 96.4%	++	N/A	N/A
2	**location tracking accuracy:** 64%	**anomaly detection**: TPR: 0.66 FPR: 0.29	+	N/A	caregivers
3	N/A	invalid measure of **weight** and **sleep**	-	server (sends update to informal caregivers every minute)	informal caregivers
4	N/A	N/A	N/A	storage in database and web application	- any computer connected to the system's network
5	N/A	N/A	N/A	- family portal - clinical portal	- resident can track his/her own data on tablet - resident can decide with which family member to share what
6	**fall detection accuracy:** 100%	**fall detection:** in 3 out of 9 houses there was one false alarm over the course of one month	++	N/A	N/A
7	N/A	"unstable system, frequent crashes"	-	N/A	N/A

[1] 1st level: bending, standing, sitting, lying down. 2nd level: centroid height, measuring the distance to the floor plane at the same time. 3rd level: position of the body's torso. 4th level: positon of the body's extremities

[2] TNR = True Negative Rate

[3] TPR: True Positive Rate

4 Discussion

This scoping literature review was conducted in order to eventually answer the question: “What are the limitations and possibilities in observational lifestyle monitoring of the elderly?”. In the following paragraphs limitations and possibilities will be described with regard to all the three research questions.

Concerning the first research question *(“What objectives do the monitoring systems pursue and how are they operationalised?”*) a clear focus on rather observable and/or objectively measurable states as physical health (vital signs, sleep patterns, weight) and emergency services (fall detection, panic buttons) was found in contrast to the low frequency of mental health measures. Especially the very subjective state of mental well-being (concerning mood and emotions) was virtually never kept track of in the seven systems. There were many possibilities found to operationalise the goal of detecting changes in physical health (using medical devices, pressure sensors etc.) and emergencies (fall detectors, motion sensors). However, a broad measure of cognitive abilities was used in no more than one of the systems.

Regarding the second research question (*“What is the reliability and validity of the different technology methods?”*) it was striking that in more than half of the compared systems no clear numbers were given that could support the statements about the reliability and validity of the system. Comparability was additionally limited because of the fact that even the studies making use of numbers did not all measure the same things. Some focused on true positive and true negative rates while others reported the false positive rate instead. However, some of the studies showed already decent reliability results, in particular when it comes to fall detection. Especially when taking the rather early developmental stage of these systems into account, the possibility to measure emergencies like falls this reliably definitely is a silver lining.

With regard to the last research question (*“How are the data of the monitoring systems stored and who can access them?”*) the information provided by the studies was meager. Although in one of the systems the resident had the possibility to distinguish between caregivers in terms of which information they can access, however in the majority of the studies no information on both data access and storage was given. This is likely due to the fact that the compared AAL systems were not sophisticated or methodologically in a sound state. The overall idea of a newly invented system was tested in a first pilot study (sometimes only by actors). Maybe that explains why the focus did not lie on privacy issues.

The trade-off of privacy, usability and safety is a huge topic when it comes to evaluating AAL systems. Often relevant information concerning these criteria was missing in the studies, raising suspicions that oftentimes the focus in the development process of AAL systems lies on the technology part. However, the importance for privacy regulations should not be underestimated. It is part of the European data protection law that for monitoring systems it needs to be stated how the data are stored, how they can be accessed and who is responsible for the data (Nordland, Sujan, Koornneef, & Bernsmed, 2015). In smart homes sensitive and highly personal data are collected. It must be ensured that these information can only be seen by the right group of people (Faanes, 2014). Thus, people who have the permission to access the data need to declare that they won't misuse it (Sánchez, & Pfeiffer, 2016). It should not be forgotten that eventually human beings are the ones making use of these monitoring systems.

But not only the need for privacy preservation should be among the main concerns. It was found that 40% of elderly people (i.e. older than 65 years) suffer from feelings of loneliness, with increasing levels of intensity the older they get (Hawkley & Cacioppo, 2010; Wolf, Scurria, & Webster, 1998). Furthermore, elderly people typically show a decline in cognitive skills as planning, reasoning, and inhibiting behaviours (Salthouse, Atkinson, & Berish, 2003). These facts underline the importance of tracking the elderly's mental health in terms of cognition and well-being.

The many health risks elderly people are facing are surely a source of stress for their caregivers. These worries about the health state add on other tasks informal caregivers typically fulfill, as reformulating health information in an understandable manner, supporting the elderly emotionally and sorting out financial affairs and insurance matters (Fletcher, Miaskowski, Given, & Schumacher, 2012). These burdens should not be expanded by unnecessary stressful events. Unnecessary stressful events are likely to happen if the sensitivity (true positive rate) and the specificity (true negative rate) are not properly cared for. Although it is unrealistic to hope for a system with a specificity and sensitivity of 100%, more attention should be given to these rates in the testing of the system. An AAL system should provide more safety by detecting occurring emergencies but it should also provide the caregivers with reassurance that everything is fine if this is the case. Both should be done accurately.

In general, the testing phase of the systems involved several critical points. In terms of the design of the studies it should be ensured that not only actors test the sensors in a simulation study but that the system gets assessed in real houses by real users. Additionally, the studies varied widely in the duration of the testing phase. Especially a sophisticated assessment of the functioning of fall detectors and other emergency detecting sensors in a real home environment requires time. It is therefore good to see that the majority of the studies lasted several months.

4.1 Limitations and Strengths

In this scoping review a total number of seven scientific articles were compared. Only one database was used to find them. This means, that a number of other applicable and accessible papers was probably missed. Together with the rudimental search string that does not involve many synonyms as “sensor technology” or “multi modal sensing system”, nor any asterisk, this might explain the small number of applicable studies. Furthermore, the decision on inclusion and exclusion criteria and also the assessment of eligibility of the found studies was performed by one person only. This may have caused mistakes in judgements about eligibility and too narrow inclusion criteria in the first place since other reviewers might have chosen additional attributes that would have permitted inclusion.

Another limitation was the restricted access to the studies. This review only includes studies that were fully readable. Therefore, only Open Access papers could be used or those that were held by the university’s library. Future literature reviews that are conducted in a broader frame than this Bachelor’s thesis could address these issues if they have the capacities to search in different databases and gain access to more papers. However, this review provides an overview of systems that were recently invented and therefore contain quite new technologies. A unique feature of this review is the inclusion of information on both physical and mental health, and privacy concerns relating to the resident’s data.

4.2 Recommendations

AAL systems have the potential to make a safer life at one’s own home possible. Especially incidences that usually make elderly people feel enormously helpless, as for example falls, can become less frightening when knowing that one is monitored by one’s carers. However, the right for privacy must not be offended here. Data have to be kept confidential.

Another thing missing in most of the systems is the focus on individual needs and concerns. This is also found in the work of Cesta, Cortellessa, Fracasso, Orlandini, and Turno (2018) who state that the focus in AAL studies is highly directed on the technology part while the usability issues play a small part. That is bolstered by the fact that also of the seven studies used in this review not all tested their systems on elderly people. Consulting actors for assessing the system’s functionality could be another sign of the rather rudimental state the invention of the system is in. However, it nevertheless gives reasonable grounds for suspecting that the end user’s satisfaction with the handling of the product is not of primary concern in the development process. And again, this neglect seems to be a big mistake, given that accepting and using the system gets more likely when users have been involved already in the design process (van Gemert-Pijnen, Peters, & Ossebaard, 2013). Acceptance of the system is of high importance. Especially because many elderly people resist to acknowledge that they might be in need of support (Uhlig & Bahrmann, 2014). Why should they use a system that they find hard to handle when they don't even see the necessity for getting help?

Thus, instead of focusing solely on assessing the functioning of the technology, among the top priorities should be a human-centered approach, a clear explanation of how data will be protected and transparent numbers for reliability and validity of the sensors. It must not be forgotten that eventually human beings are the ones making use of these monitoring systems. Their concerns, needs and wishes should be involved in the development process from the beginning on. This is what this literature review aims to show.

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