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*Article*

# Electronic Spatial Assistance for People with Dementia: Choosing the Right Device

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**Abstract:** The demographic change and ageing in Europe will lead to a growing number of people suffering from dementia. Consequently, costs for public health will increase because people become more and more reliant on care and gradually lose their independence and mobility. In the case of dementia, remedial measures could be provided by assistive technology to support independent living at home for as long as possible. Current assistance systems are often limited to actively raising an alert (*i.e.*, electronic panic buttons) or location tracking. Due to this small range of functions these systems are poorly accepted by the target group. Thus, this paper reports on a selection process for a spatial data collection device allowing the development of a new so-called mobility safeguarding assistance system for people with dementia which combines features of different systems. In particular, the wearability as an everyday object is a key issue when it comes to identifying an adequate gadget for elderly people. The proposed methodology considers user requirements as well as technical requirements when it comes to finding a suitable device. Based on these requirements, several different devices were reviewed and tested in order to find most suitable potential device as part of the selection process. The device selected shows that the proposed process on how to choose the right device performed well.

**Keywords:** mobility safeguarding assistance system; device selection; hardware selection; GPS logger selection; ambient assisted living; spatial data collection device selection

## 1. Introduction

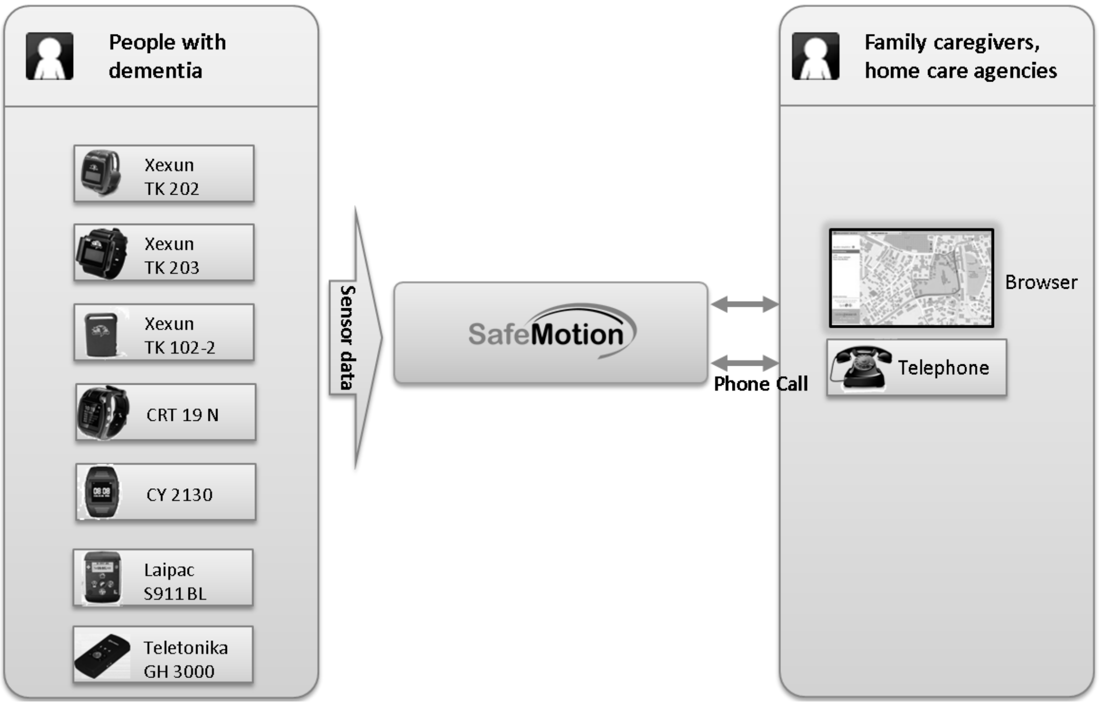
The demographic change and ageing in Europe will lead to a growing number of older people suffering from various ailments. One of the challenges in this context will be the rising number of patients suffering from dementia. In 2006, it was estimated that 7.3 million Europeans between 30 and 95+ were suffering from dementia. The number of persons affected is expected to double by 2040 [1]. The most common forms are Alzheimer's disease (60%) and vascular dementia (16%). Dementia affects the elderly person's capability for autonomous activity indoors as well as outdoors. According to the clinical dementia rating (CDR), three stages of dementia can be distinguished: mild, moderate and severe dementia [2]. At the first stage, people suffer from moderate but progressively increasing memory loss, difficulties with time-space relationships and spatial navigation even in places they are familiar with [3]. Common routes or simply taking a walk become a daily challenge. A study with dementia patients showed that 43% of the participants got lost at least once at some point [4]. As a result of the increasing sense of disorientation people become fearful and, consequently, they become more and more reliant on care and gradually lose their independence and mobility. Thus, as a result of the increasing number of people with dementia, costs for public health will increase. Based on this development, information and communication technology (ICT) and in particular geographic information systems have become more important in recent years in supporting people with dementia and their spatial deficiencies caused by the illness [5–7].

Several studies using GPS tracking for analyzing and monitoring out-of-home mobility of people with dementia have been conducted [6,8,9]. In order to increase the acceptance it appears that, in addition to GPS, complementary features such as an accelerometer or panic button need to be offered by the data collection device [10]. Aside from the case of "*getting lost*" two further aspects associated with dementia, namely "*falling*" [11,12] and "*increasing disability when handling complex problems*" [13] might be addressed in one form or another by a wearable data collection device. A fall, for example, leads to a loss of confidence in mobility and further results in a limitation of movement, all the way up to social isolation. The severe personal, social and economic consequences of accidental falls of elderly people have pushed the development of devices suitable for fall detection. Although these devices are not able to prevent the occurrence of a fall, they help to avert the life-threatening consequences of a person lying helplessly and unnoticed on the floor. In contrast to expensive systems that need to be installed in the user's living environment, small body worn gadgets have become of particular interest. Tailor-made systems have existed for a couple of years. Due to the fact that people with dementia have trouble handling complex problems and are increasingly confused, some of them currently use electronic panic buttons to be able to request assistance. So, as electronic panic buttons are widely accepted and well known this feature should also be offered by a device for people with dementia. In many cases, the limiting factor for the success of a study or a project dealing with aforementioned aspects has been the reliability and acceptance of the data collection device [6,9,14]. For this reason this paper focuses on the selection process of an extended spatial data collection device for people with dementia.

This question is addressed in the research project SafeMotion where a new, so called mobility safeguarding assistance system for people with dementia (shown in Figure 1) is developed and evaluated. As shown in Figure 1 the system is aimed at supporting people concerned with a wearable device, as well as their family and staff from home care agencies by providing them necessary information via phone and web-interface in a distressed situation. Consequently, it requires a design to work discretely in the background and only provide support in emergency situations. The following requirements are considered: complete integration into everyday objects, a minimal configuration overhead, and highest reliability of alarms in a distress situation [15]. The question, which hardware is suitable to unobtrusively deliver data while still complying with user and technical requirements, needs to be answered.

The remainder of this paper is structured as follows: In the next Section, related work is reviewed. In Section 3, user requirements are described. Section 4 deals with technical requirements. The device selection process is presented in Section 5. Results in the application of the process are shown in Section 6. Section 7 draws conclusions of this work.

**Figure 1.** SafeMotion—mobility safeguarding assistance system.




## 2. Related Work

In the discussion of related work we focus on projects and studies in which different wearable data collection devices have been used and evaluated in addressing the cases of (i) getting lost; (ii) falling and/or (iii) increasing disability when handling complex problems.

Since spatial data collection devices are continuously getting smaller and at the same time battery performance is increasing, research is conducted in the area of tracking people with dementia. First attempts were made by Miskelly [16]. A clinical trial with a GPS integrated mobile phone (Garmin NavTalk) involving 11 participants for a total of 84 weeks was carried out. Each participant had a relative caretaker, who was responsible for the proper execution of the test. Relatives had the possibility to perform location requests. According to this study the limiting factors for the system are user compliance and technical constraints whereby user compliance is dependent on technical reliability. If participants and their relatives had problems using the phone they became frustrated and refused the system. Another pilot study with people in early stages of dementia was conducted in the Netherlands [6]. 33 dyas of care receivers and caregivers integrated the use of GPS into their daily routines. GPS tracking was tested in this study but the main focus was on evaluating feasibility, acceptability and benefits of such a system for people with dementia and their informal caregivers. A majority of the caregivers were able to use the technology. However, some of the dyads dropped out of the study or rarely used the system due to technical difficulties such as insufficient battery life or localization problems. Both battery life and localization quality have also been reported as limiting factors by another case study dealing with GPS tracking for people with dementia conducted in the UK [9]. Results from the SenTra project, where 146 cognitively healthy persons and 76 persons with mild cognitive impairment from Germany and Israel were tracked [17], also show that it is not easy to motivate the elderly to wear a GPS-device and to offer an accurate system [18].

Only a few projects address the technical evaluation of different devices, e.g., the Locating Technology Project (LTP) which aims at identifying and examining existing electronic locating systems that have been designed to assist people with dementia [19]. In the project, following evaluation criteria for effectiveness, wearability and ease of use were established:

- Battery life expectancy
- Transmitter size, weight, durability, and convenience
- Range of the technology
- Reliability of the technology and/or system
- Time in which the person was found
- Time in which a signal could be found
- Training required to use the technology
- Social acceptance of the transmitter and locating technique

Unfortunately the device names and manufacturers are not given in the LTP Report.

Another project called KITE (Keeping in Touch Everyday) dealt with a user-centered approach for developing assistive technologies for people with dementia [20]. During the project, focus group workshops including 10 people with dementia, 11 caregivers and 4 Alzheimer's Society volunteers were carried out. Within the workshops, the perspectives of the persons with dementia and their caregivers were analyzed. In participatory design workshops, requirements for an assistive technology were collected. It turned out that people with dementia would like to have a system to be able to talk to someone in case they become lost or simply press a panic button. Another finding was that a mobile phone is currently not used by the end-users in case of an emergency due to usability problems. The use of an everyday object as assistive technology was pointed out. From a technological point of view it was clear that the device would require some form of tracking technology—GPS and GSM were chosen. An armband and a notepad was developed and tested. The first feedback of the users has been that the devices are too large. Furthermore, the user of the notepad was concerned that the panic button might be too easy to press inadvertently.

When it comes to wearable fall detection systems, the major requirement is that the detector should activate and operate automatically, without user intervention [14]. Wearable devices such as smartphones have the advantage over vision-based systems that they operate both indoors and outdoors. However, Igual [14] also reports that the use of mobile devices by elderly is not without difficulties because of usability barriers. Nevertheless, it is also reported that fall detectors are highly valued by the elderly.

As already mentioned, when people with dementia face an increasing disability in handling complex problems they use electronic panic buttons to be able to request assistance. These systems are widely accepted and offered by different home care organizations (e.g., Red Cross). The major disadvantage of these systems is that they do not work outdoors when people are out and about.

To sum up, the main challenges for wearable mobile data collection devices are user compliance, device reliability, battery life, robustness, size and variations concerning location accuracy.

A process for selecting an extended spatial data collection device, taking into account the requirements of all user groups (people with dementia, family caregivers and staff from home care agencies and nursing homes) as well as technical requirements, has not yet been defined. User and technical requirements necessary for the requirements catalogue used in the process will be described in the next section.

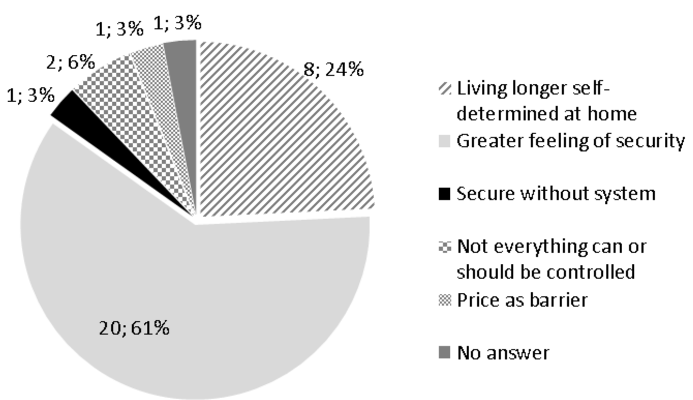
## 3. User Requirements

The user requirements for an extended spatial data collection device for people with dementia were determined by interviewing people of each user group, namely (i) potential end-users; (ii) family caregivers and (iii) home care agencies and nursing homes, and by considering results of the KITE (Keeping In Touch Everyday) and LTP (Locating Technology Project) projects [19,20]. For the interviews, as suggested by literature [21,22], paper-based interview guidelines, one for each user group, with focus on technology acceptance, device appearance and system functionality were designed. The interview results of each user group are summarized in the following.

### *3.1. Potential End-Users*

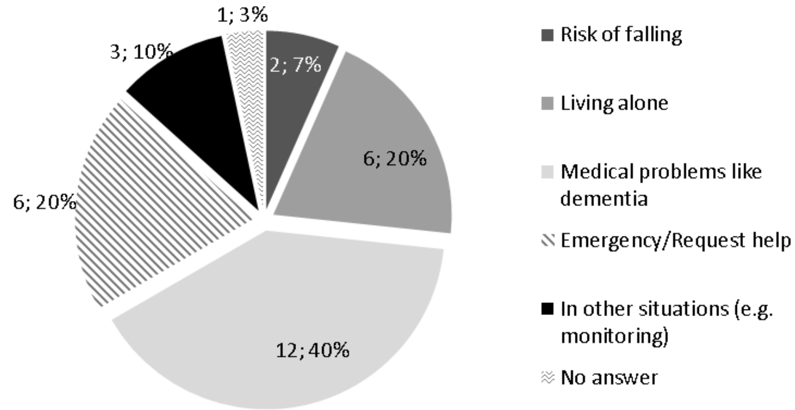
Using the aforementioned interview guidelines, 33 potential end-users (23 women and 10 men) with an average age of 70 years living in the region of Salzburg, were questioned about their assessment of potential benefits from mobility safeguarding systems. 30 out of 33 (91%) indicated that they would use a mobility safeguarding assistance system. Essentially, two reasons for using such a system where mentioned, namely a greater feeling of security (61%) and living at home self-determined for longer (24%) see Figure 2.

**Figure 2.** Reasons for or against the use of a mobility safeguarding assistance system (*n* = 33).



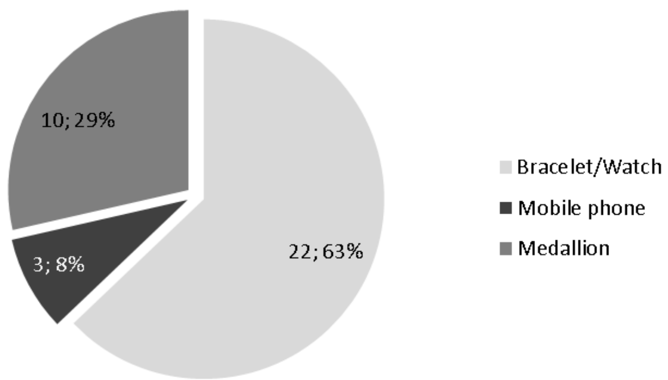
Detailed reasons for the use of such a system are medical problems such as dementia (40%) and emergency situations in general (20%) *cf*. also Figure 3.

**Figure 3.** Reasons for system use ($n$ = 30).




With regard to the shape of the device the majority of the respondents (63%) would prefer a device in form of a bracelet/watch. About 29% would use a medallion and only 8% a mobile phone (*cf*. Figure 4).

**Figure 4.** Device Shape ($n$ = 30; multiple answers possible).

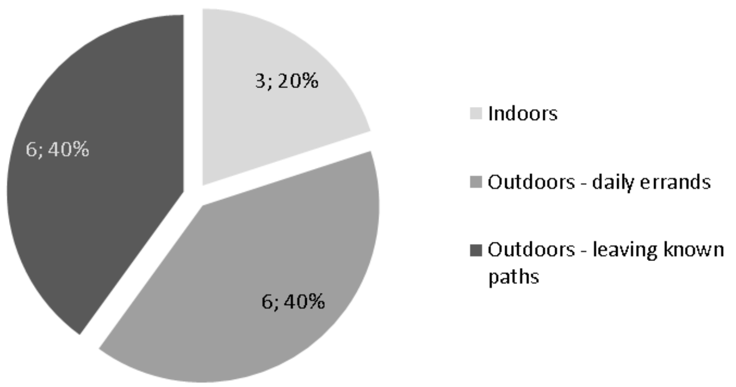



The detection of risky situations both at home and on the move can generally be considered as important. The majority of the respondents stated that in emergency situations family members (40%), their medical examiner (27%) or a rescue organization (15%) should be informed. Furthermore, 23 (77%) respondents stated that an electronic panic button including voice connection would be useful. For more details about this survey see Schneider and Häusler [10].

### *3.2. Family Caregivers*

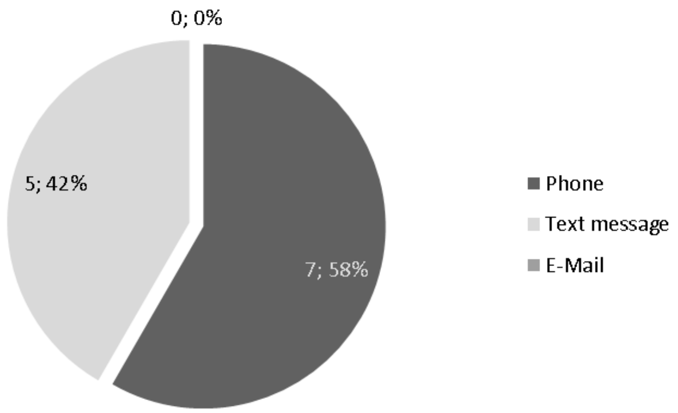
Eleven relatives (three spouses and eight children) of people suffering from dementia were questioned. Ten relatives (91%) indicate that they are interested in such a system. Forty percent of the respondents stated that such a system would be helpful when the person with dementia executes their daily errands or leaves known paths (see Figure 5).

**Figure 5.** Preferred usage (*n* = 10; multiple answers possible).



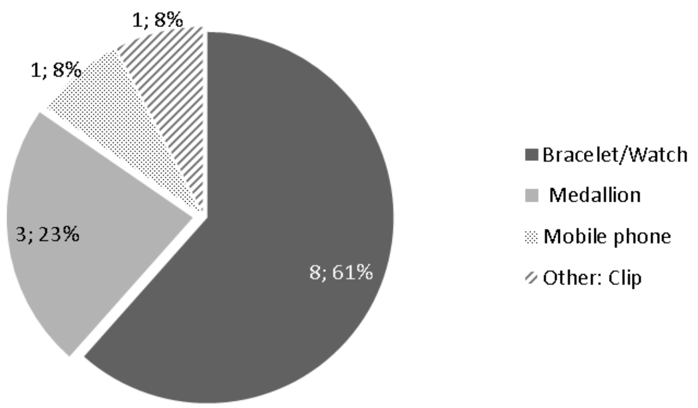

Nine out of ten relatives would appreciate if the system would raise an alert when a person gets lost. The most frequently mentioned alerting mechanism is the telephone (58%) followed by text message (42%). None of the respondents stated e-mail as an alerting mechanism (*cf*. Figure 6).

**Figure 6.** Alerting mechanism (*n* = 10; multiple answers possible).




Sixty-one percent of the respondents would prefer a device in the form of a bracelet/watch for their relative suffering from dementia. A minority of three persons would choose a medallion and only one would take a mobile phone or a clip (see Figure 7).

**Figure 7.** Device Shape (*n* = 10; multiple answers possible).

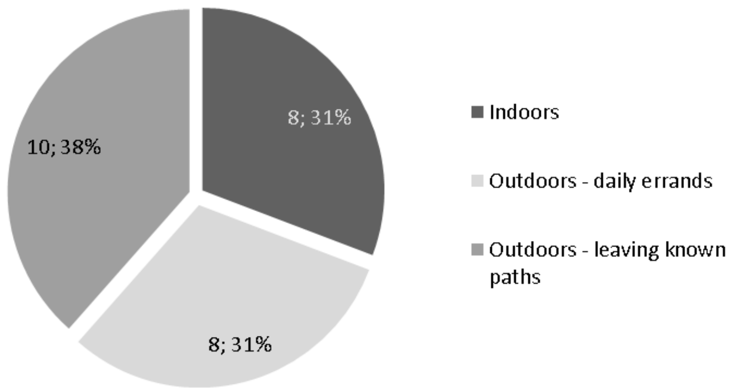


Relatives also indicated that an electronic panic button and voice connection would be useful (8; 80%). All respondents stated that an automatic alert chain would be helpful. The majority of the respondents indicated that in emergency situations family members or rescue organizations should be informed.

### *3.3. Home Care Agencies and Nursing Homes*

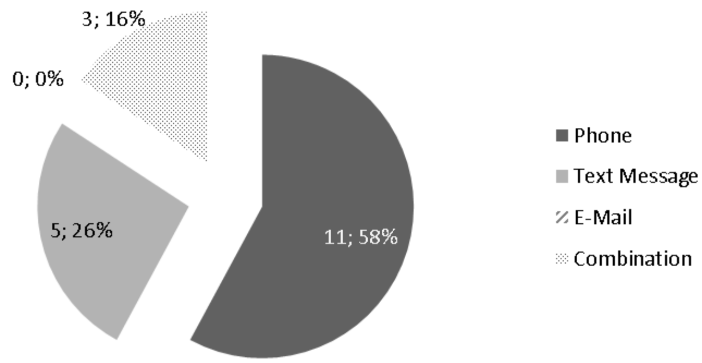
Four employees of a home care agency and nine nurses from a nursing home were interviewed. The respondents agreed that such a system would be useful if people with dementia lose their orientation during their daily errands (38%) or leave known paths (31%) see also Figure 8.

**Figure 8.** Preferred usage (*n* = 13; multiple answers possible).



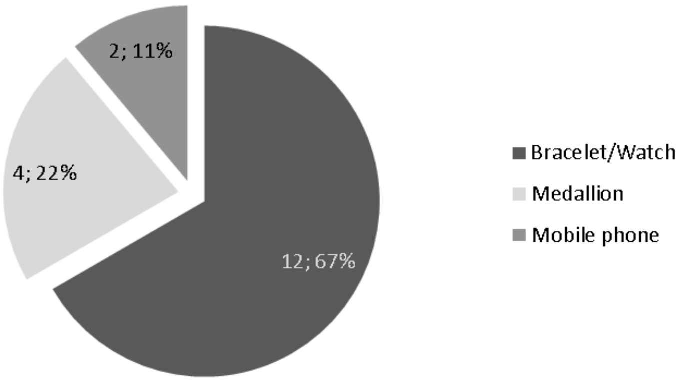

All respondents indicated that the system should raise an alert in case of a risky situation. Concerning the alerting mechanism this user group also ranked the telephone (58%) before text message (26%), while a combination of both would also be conceivable (16%) as shown in Figure 9.

**Figure 9.** Alerting mechanism (*n* = 13; multiple answers possible).




About 67% would prefer a device in form of a bracelet/watch followed by medallion (22%) and mobile phone (12%) see also Figure 10.

**Figure 10.** Device shape (*n* = 13; multiple answers possible).




All but one respondent (89%) indicated that an automatic alert chain would be useful in case of an emergency situation.

### *3.4. Derived User Requirements for the Device*

In the following, the user requirements for the device (ideally in form of a bracelet/watch) are presented. These requirements are derived from findings of the KITE and LTP project [19,20] and results of afore presented surveys. Additionally they are complemented by three expert opinions of employees of a home care agency who state their opinion concerning design and functionality of each requirement.

**Panic-Button:** More than three-quarters of the elderly surveyed reported that that a mobility safeguarding assistance system has to provide a panic button in order to request help. Additionally afore mentioned experts stated that the button must be large and easily visible, preferably in a signal color. The meaning of the button must be clear to the unaided user. Pressing the button should be possible relatively effortlessly. Nevertheless, it should not be too easy to press inadvertently as to avoid false alerts. Therefore, it should be situated on a point of the device which is easily reached but where it cannot be pressed accidentally.

**Design and Size:** For the respondents in the LTP [19] project the main reason for choosing a device was its size. Due to the built-in sensors there will be limitations in size; nevertheless according to their experiences with panic-button systems the experts of the home care agency stated that there are some requirements which should be met. The dimension of the device should not exceed 50 × 50 × 20 mm and it should not be heavier than 100 g. Controls should be highly visible and unnecessary ones should be avoided. If possible the device should be in the shape of a bracelet.

**Voice Channel:** Another requirement which came along with the panic button was the voice channel. From the perspective of the experts' both the person suffering from dementia and the caregiver should have the possibility to actively initiate two-way voice communication. The quality of the microphone and speaker should be adequate and the volume should be stepwise adjustable.

## 4. Technical Requirements

The ability to automatically detect risky situations by using a mobility safeguarding assistance system may improve the quality of life of older people and help them to live self-determined at home [23]. However, this is only true if the system is reliable and avoids false alerts [24]. As a former case study has shown that in case of "getting lost" unreliable and inaccurate locations lead to a rejection of the system [9] it is important not to trigger an alert based on a single GPS position, for example outside a defined geo-fence, but also taking into account the whole trajectory which has led to this position. Thus, in the analysis of the entire trajectory both systematic and random GPS errors [25] which might lead to false alerts can be addressed. Furthermore, it is possible to differentiate between unique (e.g., first time outside a geo-fence) and repetitive (e.g., fourth time outside within one week—always returning) movement patterns. Beyond that, accelerometer data also have to be reliable to avoid false alerts in the case of "falling". For this purpose the extended spatial data collection device should meet several technical requirements (*cf*. Table 1) which result from literature search [19,26–28] and the current state of the art regarding sensors and software development.

**Table 1.** Technical requirements.

| Technical Requirement | Description |
|---|---|
| **Localization sensor** | GPS will be used for localization. Requirements for the GPS sensor are time to first fix (TTFF) within two minutes [29], use of a satellite based augmentation system like EGNOS or assisted GPS, built-in GPS antenna, availability of accuracy information in the GPS protocol (e.g., NMEA) and GPS accuracy in the range of 5 to 10 m [30]. A standardized protocol for the transfer of the GPS positions would be beneficial. |
| **Accelerometer** | Accelerometer data will be used for fall detection. The accelerometer must be able to determine the acceleration on the three axes x, y and z. Raw data and not pre-processed data must be available. The sampling rate of the device should be approximately 16 Hz (from our data we concluded, that a typical fall is limited in bandwidth within 5 to 8 Hz [29]). Reference values for evaluation should be available. |
| **Mobile data transmission** | In order to analyze data periodically, including when a person is out and about, GSM and its extensions (e.g., GPRS and UMTS) should be used for data transmission. It should be possible to exchange the SIM card but the slot should be designed in such a way that it is difficult to simply remove the card. A basic requirement is quad-band. |
| **Safety lock** | To be able to detect whether a device is worn or not, a notification mechanism should be provided (e.g., sensors when removing or attaching the device). For privacy reasons it must be possible to switch this notification off permanently or temporarily. |
| **Battery life** | As people are expected to wear the device from getting up in the morning until going to sleep in the evening battery life should be between 12 and 18 h (more would be ideal) [16]. A notification has to be generated at a low charge state; therefore the current battery state must be available. Time for recharge should be less than 2 h. |

**Table 1.** *Cont.*

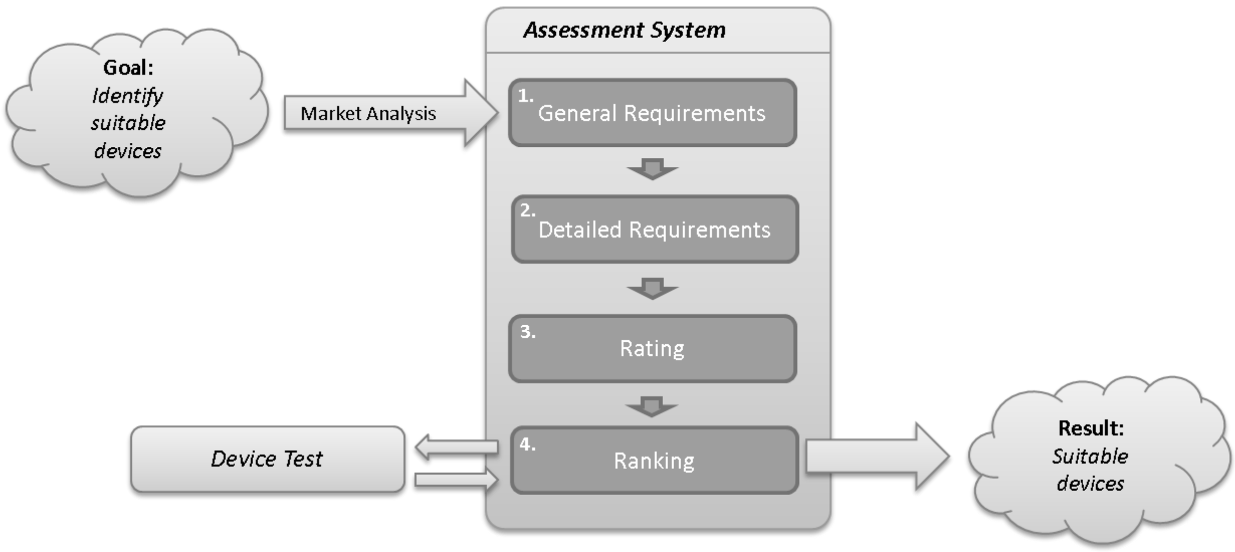
| Technical Requirement | Description |
|---|---|
| **Robustness** | The device is expected to be worn in all everyday activities which means in the shower, when gardening, *etc.* Therefore, it must be resistant to hard impacts, e.g., impact of a fall and it should be waterproof or at least splash proof and temperature-resistant (−20 °to +40 °) according to IP55 [31]. |
| **Configuration interface** | Some parameters like GPS sampling interval need to be configured before the device can be used. For that reason the device must have a configuration interface, ideally (micro) USB so that technicians can configure the device. |
| **System expandability (standard communication protocol)** | In order to be able to support more than one device with the software platform a standardized communication protocol should be provided for each device. Ideally, the transmission protocol of the device is based on communication standards (e.g., NMEA). For connecting the device to a software framework which analyses the data, sufficient documentation must be present. Furthermore a software development kit (SDK) for device connection would be welcome. For data transmission both UDP and TCP are possible, UDP would be preferred. |

## 5. Device Selection

There is a wide range of available spatial data collection devices which also have a panic button. Due to the variety of devices on the market, it is difficult to identify a suitable device which fulfills the requirements specified above. Therefore, an assessment system for device selection is introduced.

Based on the approach of the analytic hierarchy process (AHP) to structure the supplier selection problem [32] the development of the assessment system was divided into four steps, which were executed in consecutive order (*cf*. Figure 11). Before starting with step one, a market analysis of existing devices used by comparable systems was conducted. The results were used to gain an overview of the current technical possibilities and consequently prevent the definition of unrealistic technical requirements in the first step.

**Figure 11.** Assessment system.



**First Step—General Requirements**

The above listed user and technical requirements for the device were consolidated into a requirements catalogue after the elicitation and analyzing process was completed. The requirements were divided into mandatory and optional requirements, whereby only accelerometer and voice channel were optional.

**Second Step—Detailed Requirements**

Requirements which depend on the defined requirements of the first step were identified and structured as detailed requirements (e.g., mobile data transmission (GSM): exchangeable SIM card, SIM card being difficult to remove, quad-band). After having defined all these requirements with provisory detailed requirements, the requirements catalogue was tested according to correctness, necessity and benefit in cooperation with the project partners

**Third Step—Rating**

The requirements and detailed requirements were divided into mandatory (e.g., clear meaning of panic-button) and optional requirements. Mandatory requirements were by definition exclusion criterions and for the optional requirements a scoring system was developed. The scoring system consisted of an ascertained maximum possible score for each optional requirement which could be allocated entirely or partly (score 0 equates to not available and the maximum score 5 to the requirement being entirely met). For each view different maximum ratings were possible, because a device without accelerometer might never get the accelerometer score. Finally, the rating was carried out by excluding devices with unmet mandatory requirements and summing up the score of optional requirements.

**Fourth Step—Ranking**

For each view on the requirements a total of 45 devices were assessed and ranked accordingly to their individual rating. The information for calculating the score was ascertained by analysing the technical specification documents provided by the manufacturers for the devices. If relevant information was missing, it was requested from the manufacturer. The seven highest ranked devices (*cf.* Table 2) were bought for extensive tests which are described in the next section.

**Table 2.** Seven highest ranked devices.

| Device | Image | Intended Use |
|---|---|---|
| **Xexun TK203** |  © Salzburg Research Forschungsgesellschaft mbH | • Protect children and elderly people<br>• Staff safety |

**Table 2.** *Cont.*

| Device | Image | Intended Use |
|---|---|---|
| **Xexun TK202** | <br>© Salzburg Research Forschungsgesellschaft mbH, | • Protect children and elderly people<br>• Staff safety |
| **Xexun TK102-2** | <br>© Salzburg Research Forschungsgesellschaft mbH | • Vehicle tracking<br>• Protect children and elderly people<br>• Staff safety |
| **Teltonika GH3000** | <br>© Salzburg Research Forschungsgesellschaft mbH | • Protect children and elderly people<br>• Lone worker protection<br>• Asset tracking |
| **Laipac S911 Bracelet Locator** | <br>© Salzburg Research Forschungsgesellschaft mbH | • Law enforcement<br>• Children protection<br>• Healthcare assistance<br>• Elderly care |
| **GPS watch CY2130** | <br>© Salzburg Research Forschungsgesellschaft mbH | • People tracking |
| **CRT19N GPS Tracker Wrist Watch** | <br>© Salzburg Research Forschungsgesellschaft mbH | • People tracking |

## 6. Results and Discussion

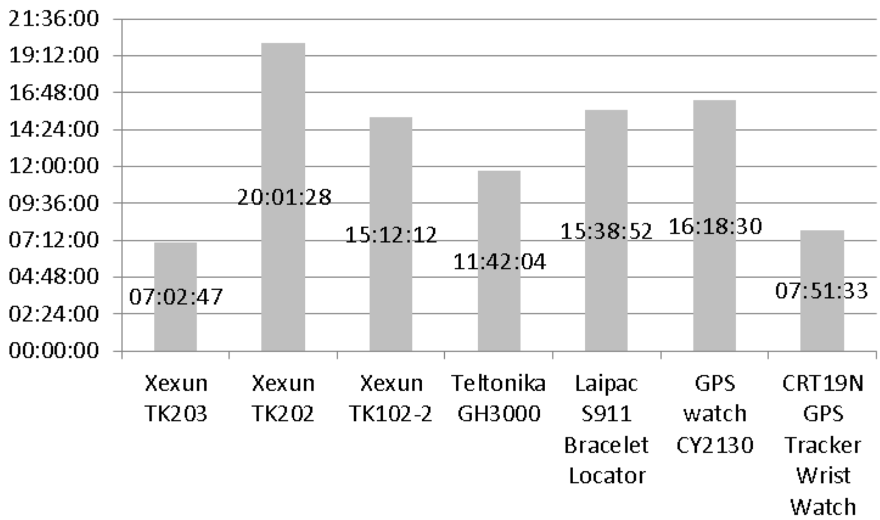
This section presents and discusses the results of the device tests. In addition, first findings of a real-world test concerning user feedback on suitability and reliability in everyday use of the device are presented and discussed.

### *6.1. Device Tests*

The seven test devices were connected to a software framework called Location Intelligence Suite (LIS: A research prototype for processing and representing geo-information data (e.g., GPS streams) developed by Salzburg Research Forschungsgesellschaft mbH—http://www.salzburgresearch.at.) through a plug-in mechanism. At this time, the first difficulties occurred because some of the devices did not use a standardized protocol (e.g., binary format or ASCII format with different separators) as specified in the technical requirements. Unfortunately, this was not clear from the documentation which was available for the device selection. To learn more about the hardware and whether it fulfills the technical requirements specific tests were conducted: battery life, time to first fix, GPS location accuracy and accelerometer sensitivity. The tests were performed with each device under the same conditions, regarding time and location of execution, as well as battery life.

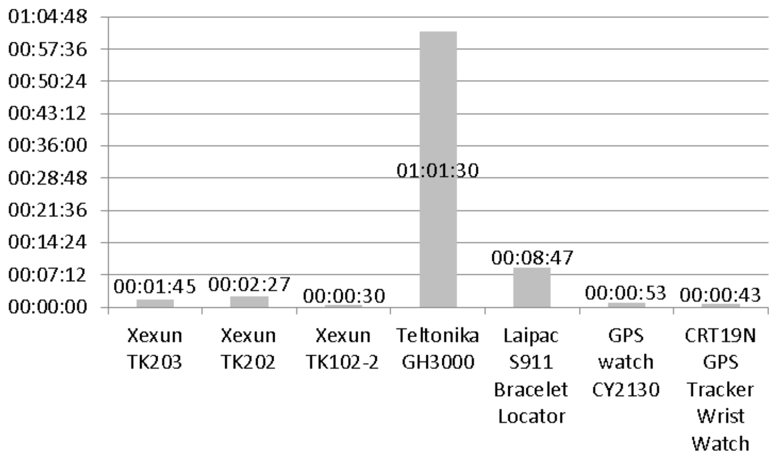
**Battery Life:** Since the devices have different recording and transmission intervals a common denominator had to be found to be able to compare the devices; in our case a recording and transmission interval of 60 s. As Figure 12 shows there were considerable differences in battery life of the devices. Only four devices met the stated requirement for battery life > 12 h.

**Figure 12.** Battery life in hours.



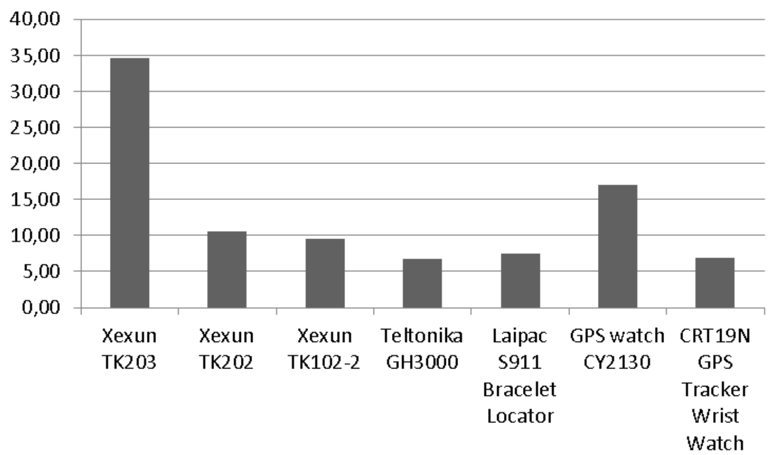

**Time to First Fix:** In our case, time to first fix was measured during a cold start. In this mode of operation the GPS receiver has no prior inputs and has to acquire satellite signals and navigation data to calculate a first position. Time to first fix was measured twice for each device. Figure 13 shows that four out of seven devices met the requirement for time to first fix within one minute.

**Figure 13.** Mean value for time to first fix in hours.




**GPS Location Accuracy:** In order to determine the location accuracy of GPS, reference points from the federal office of surveying and mapping (by name "Bundesamt für Eich- und Vermessungswesen (BEV)") were bought. At four of these reference points the GPS position of all devices was determined at the same time under the same conditions. For each GPS record the deviation to the reference point was calculated as well as the standard for each device (see Figure 14).

**Figure 14.** Standard deviation of location accuracy in meter.

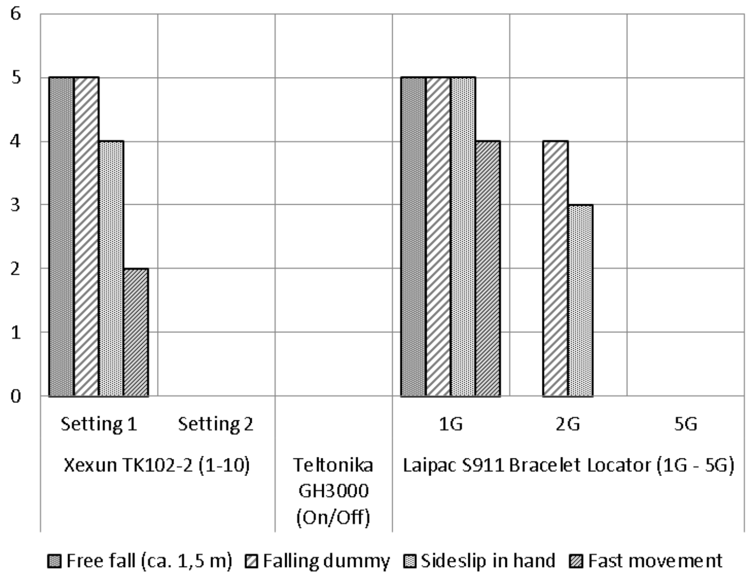



**Accelerometer Sensitivity:** Only three out of seven devices were equipped with an accelerometer. None of the devices was able to fulfill the requirement of transmitting raw data. Therefore, the following tests were performed with pre-processed data: free fall from 1.5 m; simulated fall with a dummy; and quick movements. Each test was repeated 5 times. If the device offered a possibility to change the sensitivity of the accelerometer the tests were also performed with different settings. Figure 15 shows the number of successful tests for each device and configuration. Two devices were able to distinguish between fall and none fall. Device 2 did not recognize any movement as well as device 1 in setting 3 and device 3 using the 5G setting.

It can be stated that none of the devices has fully met the technical requirements. Taking into account the user requirements, which ideally assume a bracelet/watch with a certain size/weight, a panic button and a voice channel and despite the fact that time to first fix was 8 minutes and

47 seconds (in our setting this might be acceptable as a cold start should only be done once) the choice fell on Laipac S911 Bracelet Locator. First real-world findings concerning this device are presented in the following section.

**Figure 15.** Number of fall recognitions tested with different accelerometer settings.




## *6.2. Findings of a Real-World Test*

A first real-world test with three men and five women (ø age of 80 years), wearing the Laipac S911 for about one month has already been conducted. Feedback regarding several aspects of usability and reliability has been given. First of all, there was a significant difference between men and women in the assessment of the size and weight of the device. For men the device was comparable with a larger men's watch, so they did not have a problem with its size and weight, whereas three women complained that the watch is too big and heavy for them. A problem stated by both women and men was that it was difficult for them to get the charger into the charging port. Furthermore, at least five participants had problems with the panic button. It turned out that it was too small and not as easy to press as expected. Two people also complained about the quality of the loudspeaker, saying that it was too quiet. Concerning reliability they reported that panic alerts were successful in most cases. In some cases there were problems with the GSM connection in rural areas. Due to problems with the GPS sensor the device of one participant had to be changed during the test. The fact that the device did not transmit raw accelerometer data lead to a reimplementation of the fall detection algorithm which then was not as reliable as the original had been. Finally, it has to be stressed that the majority of users were satisfied with the functionality of the device but there is still room for improvement.

## **7. Conclusions**

The variety of extended spatial data collection devices which might fulfill the user and technical requirements stated in this paper is wide. However, the selection of a suitable device is difficult. Therefore, a process for device selection had to be defined. With the above mentioned methodology it was possible to identify 7 out of 45 devices which might be suitable for people with dementia.

Through specific hardware tests with a strong focus on spatial data collection the selection could be further restricted to two devices (Laipac S-911 and Xexun TK102-2). At this point it has to be stated that these were the two best devices out of seven but also do not fully meet the technical requirements. Due to the users desire for a bracelet/watch the choice fell on Laipac S911 bracelet locator.

A first real-world test with eight users has shown that there are gender-specific differences regarding the device acceptance. This is an important point which has to be taken into account for further product development. Additionally, some other hardware challenges came up during this first real-world test and the hardware manufacturer will be asked for improvements before a larger field trial will be conducted.

Furthermore, a new requirement which had not yet been taken into account emerged during the real-world test—easy charging. As additional device requirements can be easily included in the assessment system this will be done. Hence, a reassessment of each device is possible with minimal time effort. Through this approach new systems on the market can be evaluated quickly and easily to assess whether they should be used in a later stage of the project.

Finally, it can be concluded that using the selection process presented in this paper a suitable device for real-world test has been identified. This process, considering both general and detailed requirements, combined with real-world tests, can be recommended to people dealing with similar problems in the context of selecting a spatial data collection device for pedestrians in general or in particular for people with cognitive impairments. Within the project, a larger field trial with at least 20 end-users is planned. Therefore, we hope that we are able to test with an improved hardware version. The results of both trials will be considered in the decision of whether the device will be used for a market launch of the whole system.

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## Author Contributions

Cornelia Schneider: Study concept and design, analysis and interpretation of the data, drafting of manuscript; Stefan Henneberger: Acquisition of data, critical revision.

## Conflicts of Interest

The authors declare no conflict of interest.

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