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Safety First? Users' Perception of Wearable Sensor Networks for Aging

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Abstract Population aging is considered to be one of the most significant social transformations of the twenty-first century. In this paper, we evaluate the acceptability and usability of a system designed to silently monitor the activity and condition of older adults, with a particular focus on the elderly affected by cognitive decline. The system is composed of sensors that can be hidden in various wearable objects to collect data about a user and his/her surrounding environment and transmit them to a server for further elaboration. The aim is to improve safety and independence of older adults. We conducted a survey involving elderly people, their relatives and health practitioners to better assess their needs and provide them with a technology that is as little intrusive and visible as possible. The results of our survey are promising as the majority of the respondents expressed their willingness to use the proposed technology in their everyday lives.

Keywords aging · technology · wearable sensor networks

1 Introduction

The world's population is aging. According to the World Population Prospects prepared by United Nations [9], by 2050 a quarter of overall world population will be composed of people aged 60 or above, which is already a common pattern in the European nations. This social phenomenon has profound implications for many facets of human life and forces modern societies, families and healthcare systems worldwide to face new challenges. Among the most important issues arising from the increasing life-span, age-related diseases, disabilities, cognitive decline and dementia are the most difficult ones to be dealt with [20].

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Dementia, and in particular Alzheimer's type of pathology, affects an increasing number of seniors. It is a medical condition characterized by a persistent decline in multiple mental domains [4]. It affects the individuals' everyday life and alters the former level of functioning. Even though, in the initial stage of the disease, remaining cognitive resources of patients affected by the neurodegenerative processes may still allow them to conduct most of the everyday life activities by themselves, the subjective sensation of insecurity, lack of competence can result in the feeling of inadequacy and anxiety [24]. Therefore, an assistance based on (non-intrusive) wearable sensors may increase their sense of safety and independence [14].

In this paper, we investigate the acceptability and usability of a system composed of a *Wearable Sensors Network (WSN)*, a set of very small sensors hidden in the everyday objects, which record data and send them to a server for further elaboration. The server collects and stores information, and gives an alert in case of unexpected patterns of behavior that may indicate potential danger (e.g., falls).

The proposed system is composed of three different macro components: the sensing devices, the micro server, and the centralized server. The sensing devices are designed to be hidden in clothes or accessories in order to reduce their intrusiveness. The system, except for collecting the information about the users themselves (i.e., GPS position, heartbeat or body temperature), can also collect environmental data, such as the temperature, UV level, etc. If any threatening situation is being detected, the data are sent to the micro server which aggregates them and performs a preliminary elaboration before transmitting them to the centralized server. Additionally, the centralized server provides services on the basis of received data (e.g., an alert signalizing the wrong trajectory of movement).

The main goal of an implementation of the system into everyday lives of older adults and patients suffering from neurodegenerative diseases is to improve their safety and independence. The proposed solution is also thought to be a convenient assistance for the family members and health practitioners taking care of the elderly. Even if the system components are hidden in everyday life objects, patients could feel uncomfortable being monitored. In order to better understand the needs of our end users and the features of the system required for its acceptance and success, we conducted a survey addressed to three different groups of people: the elderly, their relatives and healthcare workers. As the results are encouraging, we have also implemented a testbed to study the feasibility of the system.

2 Related work

The use of sensor networks is growing rapidly. This technology finds applications in a wide range of areas, such as fitness/wellness [1], military services [21], mobility/transportation [7], tourism/leisure [5], and health-care [2].

There are many examples of commercial devices that incorporate sensors to monitor physiological data. Fitness bands and smartwatches are good examples of this kind of products [18]. They became popular among sport enthusiasts due to the possibility to, not only track the physiological data, but also record their personal performance. We can also find some proof-of-concepts in the literature: in [22] the authors proposed a wearable training system that supports athletes in learning correct movements during their training sessions, while [13] presents a safety service for children which consists of a vest equipped with wearable sensors.

Wearable devices are often used in the medical field. They can be used to monitor life parameters, body position or location of a patient. Due to their capabilities to analyze and transfer data in real-time, they can be an invaluable help for the family and physicians taking care of the elderly [2]. For example, Amato *et al.* designed a smart bracelet that monitors data in patients affected by Alzheimer's disease [3]. Thank to this bracelet, they recorded and analyzed a database of physiological data and identified a set of features that allows to detect states of crisis. "Living weel with Anne" [12] is a project which aims to develop a virtual agent that helps people with dementia with memory problems and other cognitive related issues. The goal is to support patients in maintaining independence.

Another issue affecting dementia patients is spatial navigational difficulties [23], i.e., problems with determining and maintaining the right trajectory from one point to another [15]. For this reason, a growing body of research focuses on the application of wearable technology in monitoring patients' spatial navigation skills. Grierson *et al.* [10] proposed a tactile wayfinding device aiming to facilitate navigation for persons with dementia. A wearable belt with four small vibrating motors provides users with a tactile signal indicating the direction to their destination. A similar device was designed by Rosalam *et al.* [19]. The authors investigated the reaction of the patients to the proposed wearable device and its applicability to assist them in wayfinding. In the initial stage of the study, they also administered a preliminary survey in order to understand the design preferences of the users.

Understanding the needs, preferences and acceptability of wearable devices among the end users is essential for their practical employment. As already mentioned above, fitness bands and smartwatches gained popularity among sports enthusiasts and athletes, but what attitude the elderly people have towards them? Some research studies have been conducted in this domain. The authors of [17] faced the problem by comparing British and Japanese perception of a wearable ubiquitous monitoring device. They investigated parameters such as perceived privacy invasion and the attitude of participants towards the technology application. Unfortunately, the sample of participants includes only a limited number of seniors.

In this study, we aim to investigate how elderly people, their relatives and medical staff perceive the utilization of WSNs in improving the quality of life of seniors and patients with dementia. We created and administered a survey which inspects, not only the technical and aesthetic preferences of the participants, but also their perception of the crucial issues, such as safety and privacy.

3 Case studies

In this section we present two possible scenarios of the application of our WSN for the elderly population. We consider both the utility for healthy older adults and a group of patients with dementia. In the first case, the main goal of applying our technology is to maintain the independence of the users. In the second scenario, the aim is to increase the sense of safety in dementia patients.

3.1 Healthy older adults

The first use case presents the application of our WSN in a group of healthy older adults, who, even if healthy, often require assistance or surveillance in order to prevent life-threatening situations, e.g., accidental falls. To support older adults in maintaining a safe independence in their everyday-lives and to minimize the need for a permanent presence of a caregiver, the wearable technology can be applied.

Seniors can decide to wear their sensors in a wide variety of clothes and accessories. Due to the small size of the devices, they can be placed in jewelry, handbags or any piece of clothing. A user can share the access to the collected data with relatives or other indicated individuals, or be the only one connected to the WSN infrastructure. In this way the information about user's vital signs (heartbeat), unexpected or abnormal movements (e.g., falls), real-time position or chosen destination with a programmed, best fitted pathway can be either available only to the user or also to a specified person. If a senior using the WSN chooses to go to the bank, he/she inserts the location in the smartphone application which tracks the user during his/her movements and sends an alert if his/her behavior presents some significantly unexpected pattern.

3.2 Dementia patients

In the second scenario, the WSN is applied to the clinical settings. As discussed in [14], wandering behavior is a common problem associated with dementia. Our system can be a great help. In the initial stage of the disease, it can be used to silently monitor patients' activities, preserving their independence. In more advanced stages of the disease, it can be used in hospitals, nursing homes and other assisted living facilities. The possibility to locate the patients in real-time guarantees a higher level of safety to the patients and provides a convenient and reliable tool for the medical staff to take care of the patients. While GPS can be easily used to locate patients outdoor, in indoor situations the WSN can use the accelerometer, signal-strength, sound, etc. [11].

Patients equipped with sensors can move freely in the facility without the threat of undetected falls or alarming alterations in the vital signs. The information collected can be accessed by the medical staff through the web server.

4 Results

The aim of this study is to investigate the level of acceptability, usability and functionality of our WSN applied to the population of elderly people with a specific emphasis on patients with dementia.

We conducted a survey that targets three different groups of participants: older adults, their relatives and health practitioners. The total number of participants who took part in the study was 146: 44 elders, 51 relatives and 51 health professionals. The complete description of the survey methodology and participants' characteristics can be found in [14]. The results are presented in the following subsections.

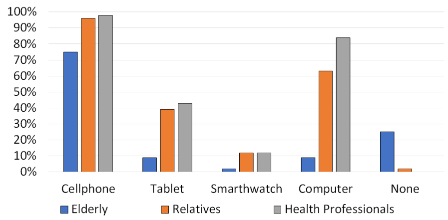

Fig. 1 Electronic devices most commonly used by each group of the participants (multiple answers are allowed)

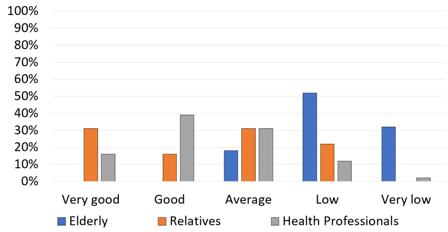

Fig. 2 The familiarity with technology of each group of participants

4.1 Familiarity with technology

We investigated what kind of technological devices are commonly used among the respondents. Irrespectively of the group, mobile phones appeared to be the most widespread technological tool (see Figure 1). In the groups of health professionals and relatives even a computer seems to have a wide appeal - 84% and 63% of participants, respectively, admit to use it frequently. In respect of the age range of the elderly group, it is not surprising that a quarter of respondents claim not to use any of the listed devices. 63% of the health practitioners, 78% of the relatives and 59% of older adults admitted that they have at least one of the above mentioned devices with them at all times.

The results obtained from the question about the most frequently used functions of the technological devices showed some significant differences between the elderly people and two other groups of participants. As both relatives and health professionals indicate text messages (SMS, WhatsApp or similar) to be the main feature they use, only 25% of older adults admit to employ this function frequently. Unlike the medical staff or relatives, they are also not used to utilize services like Google Maps, music platforms or audio/video applications. Only 6%, 3% and 14% of the elderly, respectively, indicated to use these functions. On the contrary, over 94% of older adults admit that they are making phone calls on an everyday basis.

As shown in Figure 2, an overall familiarity with technology is lower among the elderly (with 52% of the group claiming to have only a little knowledge of this area), in respect to the health professionals (55% evaluate their knowledge as good or very good) and relatives (31% claim to have either an average or very good knowledge of the field).

4.2 Wearable sensors: description and preferences

To understand where the sensors should be inserted to be worn most frequently, we asked the group of seniors what accessories they usually wear. The most commonly appearing answers were: a watch (39%), a bracelet (39%), a necklace (36%) and a bag/waist bag (25%). A direct question, with a multiple choice, regarding the best items for the sensors to be placed in was asked to all of the three groups of participants. As reported in Figure 3 both the elderly and relatives believe that sensors sewn into the clothes would be the most practical solution. For the health

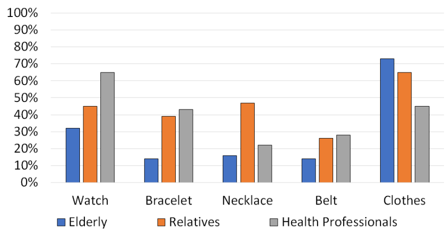

Fig. 3 Best placement of the sensors according to each group of participants (multiple answers are allowed)

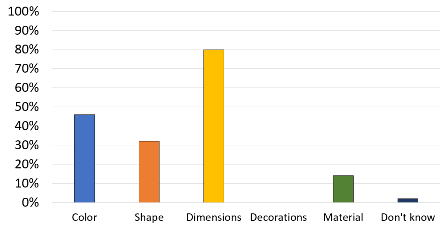

Fig. 4 Most relevant features of clothes and accessories according to elderly participants (multiple answers are allowed)

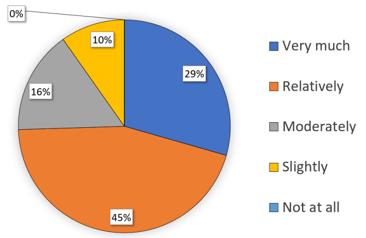

Fig. 5 Subjective evaluation of the utility of WSN for health professionals

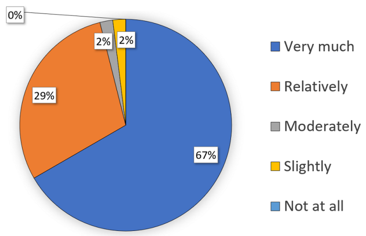

Fig. 6 Subjective evaluation of the utility of WSN for the family members

practitioners, on the other hand, inserting the sensors inside a wristwatch appears to be even more functional.

Since we aim the end users to apply our technology to their daily lives, we asked what kind of features are the most relevant for them regarding the choice of wearable accessories. For the majority of participants (80%) the size of an item is the most important characteristic. Other features to be considered are color (indicated by 46% of participants) and shape (32%) of the device (Figure 4).

Opinions about the usefulness of the system vary according to the target group: 70% of the elderly respondents evaluate the proposed technology as highly useful, whereas 82% of health professionals admitted it would be relatively (35%) or very useful (47%) for the family members or caregivers of older adults and patients. A subjective estimation of the utility of the system for their own purposes as healthcare workers is reported in Figure 5. The majority of the relatives consider WSNs as highly useful both for their loved ones requiring assistance (73%) and for themselves as caregivers (67%, see Figure 6).

The elderly, asked to evaluate predicted changes in their sense of safety due to the usage of our technology, admitted that it would increase significantly (75%). Only 4% of the respondents do not expect to feel more secure as a result of applying the WSN to their everyday lives (see Figure 7). Most importantly, 91% of older adults responded that if they had a chance, they would use the proposed devices and 89% agreed to wear them every day.

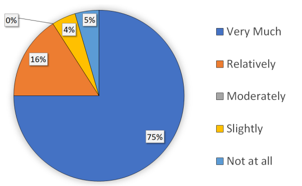

Fig. 7 Predicted increase in the sense of safety, as a result of using WSN, estimated by the elderly group

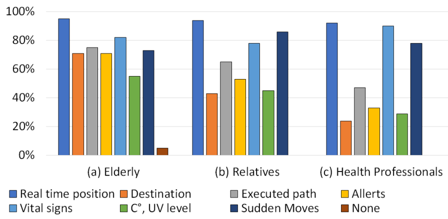

Fig. 8 Shareable information: information that the elderly would agree to share (a), information the relatives (b) and health professionals (c) would like to have an access to

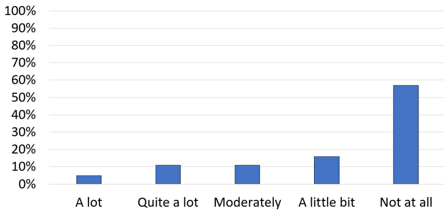

Fig. 9 The extent to which older adults would feel monitored using WSN

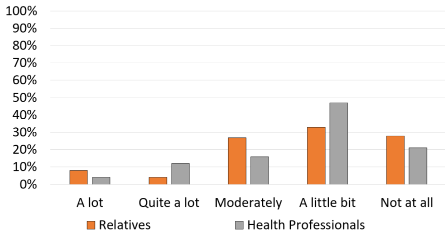

Fig. 10 Level of discomfort for the elderly in using WSN estimated by health professionals and relatives

4.3 Shareability of information

We aimed at understanding whether the expectations of the relatives and health professionals about the data accessible to them meet the willingness of the elderly to share them. Therefore, we asked the first two groups what kind of information might be useful for them, and the group of older adults what data they would agree to make available to others. Each person could have indicated more than one option. As reported in Figure 8a the majority of seniors agree to share all of the outputs that the relatives and medical staff consider relevant (see Figure 8b and Figure 8c, respectively).

According to 78% of the health practitioners and 67% of family members, the best receiver of the alerts and records in case of an emergency would be an emergency contact specifically indicated by the end user. Most of the older adults state their willingness to decide what kind of data they share (91%) and when (93%). 82% of the medical staff and 69% of the relatives agree that the elderly should be in control of what information to share.

In order to make sure that our target group would not experience any kind of discomfort using the proposed technology, we asked the respondents to what extent they would feel monitored. As reported in Figure 9, 68% of the participants answered either 'not at all' or 'a little bit' to this question (57% and 11%, respectively), which shows that an actual level of discomfort experienced by the elderly is even lower than estimated by the relatives or medical staff (Figure 10).

4.4 A deeper insight into the needs of medical practitioners

An additional part of the survey addressed to the medical staff included two open questions, giving them an opportunity to express themselves more broadly.

They were asked what kind of patients would benefit the most from the WSN and what possible applications the system may have. The most commonly appearing answers for the first question were: older adults (especially if living alone and being relatively independent) and dementia patients with different types and severity of neurodegenerative diseases (with most common reference to the Alzheimer's disease). More precise description of the conditions affecting this group of patients (i.e., memory and spatial orientation problems) were further specified by the respondents. Among the other replies indicating potential users of the system, the answer most frequently brought up was patients suffering from various types of chronic diseases. Nosological entities, such as, diabetes, cardiovascular diseases and breathing problems, were acknowledged together with psychiatric diseases and physical disabilities as conditions whose outcomes can be mitigated by the employment of the WSN.

The second open-ended question addressed to the medical staff regarded potential applications of the WSN and type of data that might have a practical use for healthcare. The most frequently occurring responses referred to locating the position of the patients affected by wandering behavior, monitoring vital signs (i.e., saturation, heart rate, blood sugar level) and falls prevention. According to the respondents an implementation of this kind of a system would allow the patients to stay more independent and autonomous, without increasing the risk of life-threatening events.

An important possible application of the WSN, emphasized by the health professionals in addition to monitoring and prevention, was rehabilitation. They pointed out that a feedback sent to the user, including errors and difficulties presented during an execution of a path, could result in an improvement in spatial navigation.

5 System description

Given the encouraging results of the survey, we implemented a testbed to study the feasibility of the system. The architecture that we plan to use for the WSN is very simple and flexible, so it can be easily adapted to the case studies presented in Section 3. Now we will discuss in brief the structure and the nodes that compose the chosen architecture, as well as the promising results related to the accuracy and energy consumption obtained by a prototypical testbed.

5.1 System architecture and interaction flows

Each element of the WSN represents a node with specific equipment, functionalities and dimensions. An example of WSN can be seen in Figure 11. The first category of nodes are the *Components*, that are nodes with the ability to detect and/or visualize data but that are not directly involved in computational activities; e.g., devices that can collect information about the UV level, GPS position

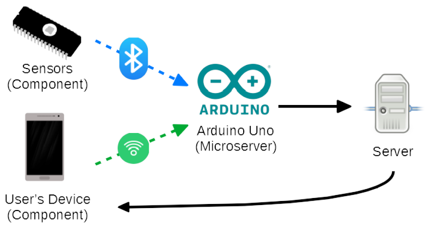

Fig. 11 An example of the wireless sensors network used during the measurements

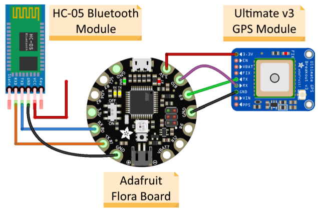

Fig. 12 An example of a node used in our testbed

or environmental temperature with their sensors, as well as the smartphones that can be utilized to visualize information and alerts.

Microservers collect data generated by components with the goal to send them to the centralized servers. In this way, the high amount of data generated by the sensors can be stored, filtered and processed before sending it to the centralized servers. We aim at limiting the energy consumption and reducing bandwidth usage by performing these preliminary operations to the data.

The *Server* performs complex operations; data are stored, aggregated and processed to offer contextualized and personalized services to the final users.

To have a better idea of how the nodes interact, we will now describe the interaction flows that occur between them. *Components to microserver* interaction transports the raw data acquired from the sensors to the microserver without any kind of preprocessing. *Microserver to the server* is the flow that sends the preprocessed data to a destination server. In respect of the previous one, the frequency of the interaction is lower. Finally, the *server to components* flow represents the interaction between the server and the users' devices. It is used to offer digested data, e.g., the followed path, the services that provide information helping with the navigation through the city, and warnings.

5.2 Testbed description and results

To validate our architecture, we inspected specific parameters of a WSN. We hence created a testbed using Arduino boards and sensors in order to assemble the component and microserver nodes (Figure 12).

Arduino is a hardware platform that offers an ecosystem of devices that are small and cheap, and can be sewn into clothes and accessories such as bags or hats. In details, we assembled three components (the UV recorder, the GPS tracker and the temperature, humidity and pressure recorder) and we used the wearable boards Arduino LilyPad and Adafruit Flora. These boards allow us to reduce the size and weight of the nodes. The microserver was created with a standard Arduino Uno board as it needs more computational power than the previous nodes. However, the small size and weight of this node can also be preserved.

The critical issues of such devices are related to the reliability of the data and energy consumption [8]. Therefore, we decided to perform preliminary tests without the involvement of users to analyzed the data collected by a wide range of sensors, i.e., UV level or GPS position, and measured the energy consumption of the nodes.

Localization error of the GPS Module				
Date	Time	Detected Position	Real Position	Error (m)
04/06/2017	18:25:40	45.892815 12.082536	45.892830 12.082583	5.11
04/06/2017	18:25:40	45.892830 10.415869	45.892830 12.082583	128983

Table 1 An example of a GPS error introduced by the HC-05 Bluetooth Module

The tests were performed outdoor and in different environment's conditions. It emerged that sensors measuring UV level, temperature, humidity and pressure are quite precise even in different environments and the data collected do not need particular elaborations. The GPS sensor, instead, reveals some issues. This kind of components are generally created to be small, cheap and energy conservative, so they are not as precise as those ones present in more expensive devices (e.g., GPS navigators or smartphones). The GPS measurements were performed both in an open environment without obstacles and also in proximity of trees and building. As expected, we identified some errors in localizing the exact GPS position, e.g., covering a distance of 120 km in only 10 s (Table 5.2). Therefore, pre-processing operations are needed to clean the sensed data from errors.

In the current version, no specific energy optimization has been yet achieved and the nodes collect samples regardless of users' activity. Nevertheless the measures of energy consumption are promising. We monitored the energy consumption of the four nodes that form our WSN testbed through a specific hardware (the Power Monitor, produced by Monsoon Solutions Inc.). As a result, we are able to understand if a specific type of battery is adequate for the monitored node and its purpose. In Table 2 we can observe the energy consumption of two different boards equipped with the related sensors and communication modules, respectively the microserver node and the GPS node. The estimated battery life of the two nodes are 8.65 hours and 17.12 hours, a good result that gives to the system a sufficient energy autonomy for a usage during the everyday activities of a user.

Energy consumption for microserver and GPS node		
	Arduino UNO + BT + Wi-Fi	**Flora + BT + GPS**
Energy Consumption [mAh]	63.6	8.9
Average Power [mW]	944.82	132.30
Average Voltage [V]	3.71	3,71
Battery Capacity [mAh]	2200	610
Estimated Battery Life [h]	8.65	17,12

Table 2 An example of energy consumption of two boards (microserver and GPS node) equipped with the related sensors and the communication modules

6 Conclusion

Older adults are generally excluded from the discussion of modern technology as they are rarely considered to be a target audience of new technological solutions. However, the results of our study suggest that this might be a misconception. Even though an average level of familiarity with technology among the elderly respondents was claimed to be low, the vast majority of them expressed their willingness to use the proposed WSN in their everyday lives. They predict that an employment of the system would significantly increase their sense of safety. Consequently, most of the elderly people who fulfilled the survey declared they would wear items with sensors on a daily basis.

The most relevant characteristics of the device, indicated by the group of older adults as influencing its acceptability to the highest extent, appear to be its size, color and shape. These features are in line with our initial assumption that proposed technology should be as little intrusive and visible as possible in order to be applicable. Sewing the sensors onto the piece of clothing revealed to be the most practical solution as stated by the relatives and elderly respondents. We must note here that the solution proposed by the medical staff, i.e., the use of watches or bracelets, seems to be more feasible, both for technical problems (i.e., clothes need to be regularly washed, and this could be a problem if there are sensors and/or board sewn into them) and for higher costs (i.e., each patient can have a single bracelet but needs several clothes to cover an entire week).

Investigating potential privacy issues of a WSN was one of our main objectives, as it is considered to be one of the fundamental problems of wearable technologies [6]. Based on the obtained results we can state that the elderly people do not consider sharing the data collected by the system with their relatives or health professionals as a problematic issue. However, having control over the privacy settings was indicated as a highly appreciated feature.

All in all, our WSN was met with a general approval. All three groups of respondents claim that the proposed technology is an innovation that may positively influence everyday lives of both older adults and their caregivers. Obtained results confirmed that our WSN may have a wide range of applications in the medical field. Possible employments suggested by the health practitioners are in line with our initial assumptions about the utility for patients affected by cognitive decline, dementia and the population of older adults in general. Some of the ideas proposed by the health professionals may also indicate further development of the project. Using WSN as a tool not only for the prevention, but also rehabilitation of the patients could be an important step forward. Furthermore, given that the final users of the information provided by our system are represented by medical staff and patients' relatives we intend to measure their level of accessibility [16].

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