A Non-intrusive IoT-Based Real-Time Alert System for Elderly People Monitoring

Hugo Martins[1], Nishu Gupta[2](✉), and M. J. C. S. Reis[3]

[1] University of Trás-os-Montes e Alto Douro (UTAD), 5000-801 Vila Real, Portugal
[2] Chandigarh University, Chandigarh, India
[3] UTAD/IEETA, Vila Real, Portugal
mcabral@utad.pt

Abstract. Typically, elderly people may be living alone for part of the day or full time, and may have difficulties or problems with mobility, but they want to maintain their independence and autonomy. Internet of Things (IoT) technology may be used to contribute to increasing the degree of security of these people in their own homes, in a much more discreet and non-intrusive way than the typical commercially available systems, providing real-time data about the status of these people to their family members or caretakers. In this article, a non-intrusive IoT-based real-time alert system to be used by elderly people is proposed, using simple and low-cost "of the shelf" electronic components. It is also intended that this solution can integrate other monitoring devices already available on the market, such as bracelets, video cameras, robots, among others. Both laboratorial and house-hold tests have been conducted to prove the effectiveness of the system.

Keywords: IoT · Non-intrusive · Real-time alert system · Elderly people

1 Introduction

All over the world, people are living longer and it is prognosed that in Europe by 2060 one third of the population will be aged 65 and above, with many of them having some kind of disability or limitations, requiring different forms of care [10]. Unless a big change is introduced, the limited number of caregivers will not be able to respond to the care demands. As such, providing high quality care services is becoming one of the biggest challenges of contemporary societies. One possible solution is the use of assistive technologies to support people in their own homes or even in assisted living facilities. There are two main objectives in the Ambient and Assisted Living (AAL) research area: monitoring solutions providing information used for detection of emergency situations (e.g., a fall or illness) and/or for detection of symptoms indicating that such situations may happen

S. Paiva et al. (Eds.): SmartCity360° 2020, LNICST 372, pp. 339–357, 2021.
https://doi.org/10.1007/978-3-030-76063-2_24

in the future; and direct support of elderly people in their everyday life. The first one, monitoring, can be implemented using positioning systems, which may also deliver useful information about the elderly person health. Consequently, the development of monitoring systems should be made having in mind the aim and place where the system will operate. The resulting information can be used for different purposes, being activity monitoring one of the most used [8]. The collected data allows for the determination of physical activity periods. For example, information on walked paths can be useful for behavior analysis (e.g., determination of occupancy periods of particular rooms), and walking speed (e.g., analysis of data in the time domain). The information of the gait speed is very important, because it depends on the health status of the elderly. It should be noted that the elderly person gait speed is typically very low, usually not higher than 1.2 m/s, and values lower than 0.6 m/s increase the likelihood of health issues (see, for example, [22,24] for the influence of various diseases on gait disorders). These systems can also be used in other type of impairments, such as wandering patterns [14,17].

Later data analysis helps to detect abnormal situations resulting from health problems or accidents. The processing of the collected data allows the comparison of the person's behavior against an assumed model. The difference between the model and the current person's behavior may be used to trigger alerts, that are usually sent to the caregivers of the monitored person [8]. The purpose of the collected data has crucial implications on the requirements concerning the tracking system's accuracy. For example, in case of activity or room occupancy evaluation, determination of position with room accuracy is sufficient. However, if the system is used for gait velocity tracking, positioning meter or even sub-meter accuracy is crucial, whereas for wandering detection the precision of localization results is of paramount importance.

The most important barriers concerning technology acceptance are discussed, for example, in [27]. The acceptance of the system is the most important and a crucial factor, determining the success of the monitoring. Preserving privacy, trust, declared functionality and low cost of the devices and services are on the top of the list of elderly users' and caregivers' acceptance criteria. If the devices performing the monitoring is to be wear by the elderly person, its use must be accepted by the user. One way to gain elderly users' acceptance is to provide the user with a wide variety of forms of tags and ways of wearing (e.g., simply carried around in a pocket, wristbands, pendants, devices attached to a waist belt). Obviously, the size and the weight of the devices should be minimized.

Obtrusivity of the system infrastructure is another very important factor. A typical infrastructure of the monitoring system consists of several "sensing nodes" (performing the measurements) and a "controller" (processing the measurement results, calculating the localizations of the elderly person—or, more precisely, the location of the tag, etc.). These systems are typically deployed in the already furnished homes, and so any changes to the interior design, such as connecting the devices with cables or moving the furniture, should be avoided.

Another important issue related to the system exploitation is the tag's energy consumption. However, because the system presented here does not rely on the use of any kind of tag, this issue will not be discussed here.

Requirements for positioning systems intended for AAL applications are discussed in [7]. The environment where the system is installed has a significant impact on the tracking accuracy and system reliability. For example, building materials, pieces of furniture and other interior design elements determine propagation conditions influencing signals delays and levels, which may reduce the performance of the system. In some cases, tracking errors can be reduced by changing "sensing nodes" locations.

The system proposed here aims at being a real-time, non-intrusive, IoT-based alert system for monitoring elderly people. Activity and room occupancy evaluation is its major concern, so that determination of position with room accuracy is sufficient. Additionally, the system is to be developed using simple and low-cost "of the shelf" electronic components. However, it is also intended that this solution can integrate other monitoring components commercially available on the market, such as electronic bracelets for measuring heart rate, video cameras, robots (e.g., medication intake), among others.

2 Related Work—Indoor Localization Systems

In [18] the authors use broadband ultrasonic signals to implement a high accuracy 3D indoor positioning system. They used low cost transducers to produce acoustic chirps of between 20 and 45 KHz as pulse signals. Then, by using synchronized ultrasonic anchor nodes and time division multiplexing to share the medium, they build a GPS-like system for indoor pervasive applications. They have performed a set of experiments to evaluate the proposed system and 3D position estimates were obtained with an absolute standard deviation less than 2.3 cm, and a position refresh rate of 350 ms.

Narrowband radio technologies are the most used radio positioning systems. Due to its low power consumption, Bluetooth Low Energy (BLE) seems to be one of the most popular. For example, the system described in [2] is based on wristbands and smartphones. The system uses "SensorTags" from Texas Instruments and it was tested in 17 elderly houses, and achieved a rate over 86% of correct room detections.

In the approach described in [16], the location of a smartphone is determined in respect to three BLE beacons. With the implementation of an algorithm based on Received Signal Strength Indicator (RSSI) and step detection, the authors achieved sub-meter accuracy. However, the measurements were performed in strictly defined conditions, with the smartphone kept in a fixed position.

Another popular class of tracking systems is based on the use of the Wi-Fi standard, which typically utilize a fingerprinting approach. In [4] a system of this class is presented, where a smartwatch is being localized using machine learning algorithms. The authors achieved room accuracy localization during tests in five flats. However, due to reception of Wi-Fi signals and intensive processing, the authors faced energy consumption problems. Sub-meter accuracy was achieved, using only static measurements carried out in a university building, in another example of a Wi-Fi positioning system presented in [25].

ZigBee-based systems for the localization of people and goods are also available. For example, three simple positioning algorithms, in-Max, Trilateration and Maximum Likelihood, were presented in [5]. The authors have conducted tests with ZigBee modules in five different environments, achieving few meters positioning errors. In [9] the localization of elderly people was simulated, and additionally using an artificial neural network. With these simulations the authors achieved positioning errors in the order of centimeters, assuming a propagation channel model.

A combination of these three technologies, ZigBee, Wi-Fi and Bluetooth, was investigated in [6], where multilateration and Viterbi algorithms were used for position calculation. The authors have performed tests in an industrial environment and a hospital. Measurements were performed in static conditions or with an autonomous vacuum cleaner positioning, and the localization errors were in the order of a few meters; the authors have not conducted any tests with persons carrying the tags.

Systems using Ultra Wideband Radio (UWB) to determine the positioning of people and goods are able to provide excellent localization accuracy. The laboratorial tests performed in [12] confirmed positioning errors lower than 0.2 m. In [11] the authors have performed tests in a nursing home with elderly people, and they were able to identify patients' behaviors. In [21] a radio frequency identification (RFID) reader was designed to simultaneously track multiple persons. The authors conducted experiments, and achieved positioning errors below 0.2 m.

The IEEE 802.15.4a standard and the availability of the compliant chips increased the interest in the UWB-based localization. The solution presented in [13] obtained sub-meter accuracy. In [19] the authors describe an implementation of a system that uses the transmission of combined chirps, also defined in the IEEE 802.15.4a standard. They achieved a localization error lower than 1 m, with a probability of 70%, in laboratory tests.

Energy consumption of these systems used for indoor tracking purposes of people and goods is a real issue, particularly if the system is to operate for long periods of time. Most of the systems require periodic battery recharging or replacement, this being a task very difficult to perform by elderly people. Only a few of the above cited systems addressed and discussed this problem. Additionally, although the systems presented above can collect useful information in AAL applications, the number of practical experiments performed in real scenarios is relatively small, with most of them being tested in laboratorial conditions.

In [26] a review of wearable technologies used for elderly persons tracking is presented. A comparison of available technological solutions, along with different criteria (e.g., accuracy, power consumption, need for the device on user side) is also presented. The number of published journal papers reviews every year in the field of indoor positioning technologies for the tracking of people and goods is very high. See, for example, [1,3,15,20] and [23], to name only a few.

The system described in the next section has no need for periodic battery recharging or replacement, and was tested in a real home scenario.

3 Conceptual Description of the System

As stated above, it is wanted to present a non-intrusive, IoT-based, real-time alert system to be used by elderly people, using simple and low-cost "of the shelf" electronic components. Additionally, it is also intended that the software component of this solution, described below, can integrate other monitoring devices already available on the market, such as bracelets, video cameras, robots, among others.

Figure 1 provides a general conceptual overview of the system. As can be seen, the detection sensors are wirelessly connected to the gateway controller. In the case presented in this figure, passive infrared (PIR) sensors, bed sensors and a Panic Button are all connected to the gateway controller. The gateway controller is connected to a cloud server. If no activity is detected for periods of time superior to the ones established and stored in the data base, an alert SMS will be sent by the server to the mobile application (App) installed in the smartphone of the caregiver. The caregiver uses this App to get real-time information about the status of every sensor, the latest detected activity, etc., and receive alert SMS. As can be seen, the system is conceptually divided in two main components: the hardware component and the software component.

In the hardware component all the different type of sensors and devices are included, like, for example, passive infrared (PIR) motion sensors, water flow sensors, switches sensors, door opining sensors, bed movement sensors, panic button, among other, and the gateway "controller", with pre-processing and communications capabilities. Note that the system is intended to work with all these and other sensors installed, or with just one type (e.g., PIR motion sensors). In fact, the results presented below were obtained with the system presented in Fig. 1, using only PIR motion sensors, one bed sensor, and a panic button. In Table 1 the components used, the manufactures, and the price of each IoT-based hardware component used in the experiments can be seen.

The software component was designed using a server-side application and a mobile (smartphone) application (App). The server-side application includes the databases, where all the data sent by the detection sensors are stored. The data stored in the data bases include the sensor's name, identification (ID), and its location, and for each activity detection the ID of the sensor who have triggered the detection, and the date and time of the detection are stored. Also included in the server-side application are the software modules responsible for the detection of potential alert situations, which trigger the sending of warning SMS to the

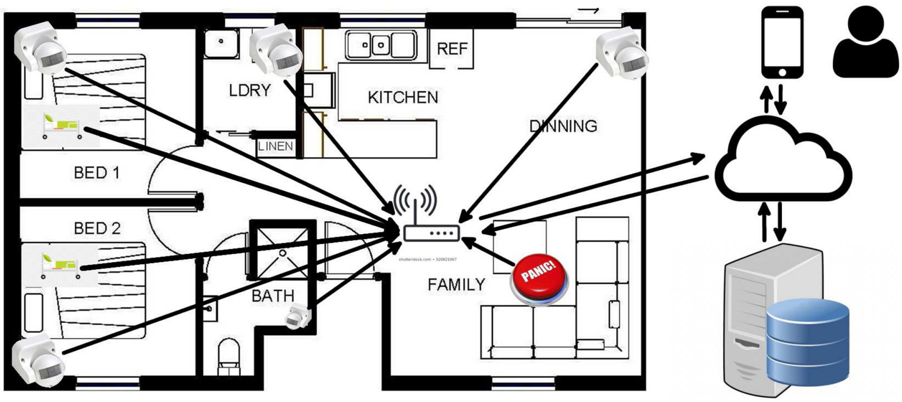

Fig. 1. General conceptual overview of the system (refer to the main text).

Table 1. Manufacturers, price, and type of the IoT hardware components used in the tests of the setting presented in Fig. 1.

Component reference	Manufacturer/Seller	Price (€)	Type
PIR motion sensor	DIGOO	7	Mandatory
Door opening sensor	DIGOO	5	Optional
Panic Button	DIGOO	3	Optional
Bed sensor			Optional
MPR121 board	NXP	3.38	—
RN2483	Microchip	11	—
0900AD54B2450E	Johanson Technology	3	—
AMS1117	Advanced Monolithic Systems	0.05	—
USB connector	TE Connectivity	1.74	—
Copper strips	—	0.20	—
Gateway controller			Mandatory
TTGO T-CALL V1.3	LILYGO	15	—
LM2596	Texas Instruments	0.50	—
RXB12 RF 433 MHz	EEant Technology	0.80	—
PIC16F1704-I/SL	Microchip	0.90	—
LoRa Module RFM95	RF Solutions	17	—
0900AD54B2450E	Johanson Technology	3	—

caregivers. For example, typically an elderly gets up in the morning, leaves the bed, goes to the bathroom, and then he/she goes to the kitchen to prepare its breakfast; if no activity is detected on the kitchen sensor after, say 15 min, nor any movement is detected in the bathroom at the end of this time, then an alert SMS is sent to the mobile App.

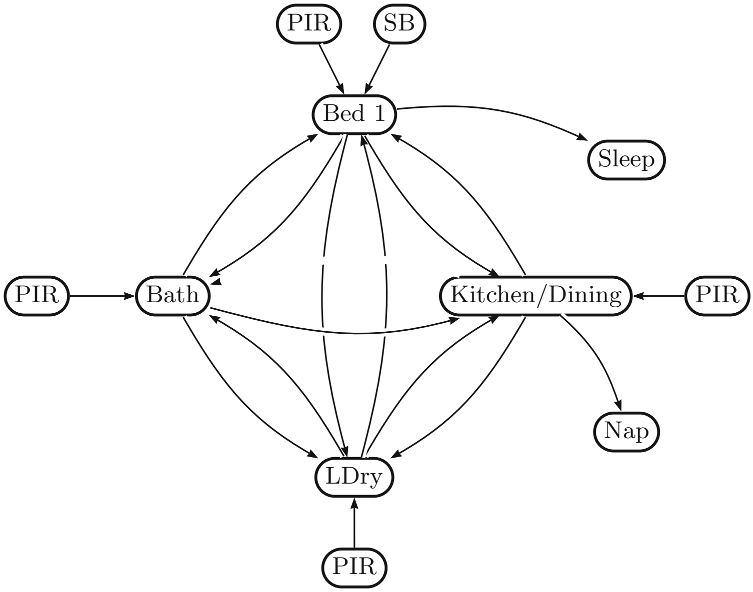

Fig. 2. State machine representing the potential alert situations that may occur to trigger the sending of SMS to the caregivers.

Figure 2 represents the state machine implemented during the tests presented below, reflecting the possible alert situations that can occur. For example, if the sensor bed "detects activity" and the corresponding PIR sensor (installed in the bedroom) detects no activity for a period longer than 5 min, the system enters the "sleep mode" state. This sate will be leaved only if the PIR bedroom sensor detects any activity or the total number of configured sleeping hours is achieved. In this last case, if no activity is detected by the PIR sensor and the total number of sleeping hours is exceeded, then an alert SMS is sent to the caregiver. Note that the state of sleep can also be entered, for example, after lunch, where typically the elderly person sits on their sofa to watch a little television and ends up falling asleep. However, in this situation the total sleeping time will be much lower, and the corresponding alert SMS will be sent if this different time threshold will be exceeded. Each of the individual sates has a different alert threshold time that triggers the sending of alert SMS when that value is exceeded. It should also be noted that the systems keeps periodically re-sending the alert SMS, if the "no activity detected" situation continues to be verified.

By using the mobile application the caregiver can check the status of the different sensors in real time, check for the last room in the house and time where activity was detected, set different threshold times for each of the states (rooms), receive/read the warning SMS, among other things.

4 Tests and Results

To test the principles and functioning of the proposed system we have implemented the practical situation depicted in Fig. 1, in a real house (flat); we have not used the sensors presented in bedroom 2 in this figure (in fact, the room was locked). The corresponding sate machine is represented in Fig. 2, and the IoT hardware components are the ones presented in Table 1.

In this particular case, all the detection sensors and controller use wireless communications. As such, there is no need for the installation of cables or any other kind of home works. All the sensors are powered by the grid network, using power adapters. These sensors can be battery powered, but then they have to be periodically replaced, with all the associated problems discussed above.

Figure 3 presents a diagram and Fig. 4 presents a photo of the gateway controller implemented, using only "of the shelf" IoT components. We have used GPRS, using a GSM modem with an IoT global operator (Things Mobile™) SIM-card, for the communications between the gateway controller and the server-side application, and the communications between the sensors and the gateway controller were implemented using RF 433 Mhz (RXB12 EEant Technology™) super-heterodyne receiver, with encoding EV1527. By using the Things Mobile™ SIM-card there is no need for the installation of an "Internet pack service" by a communications provider, with a typical much higher cost.

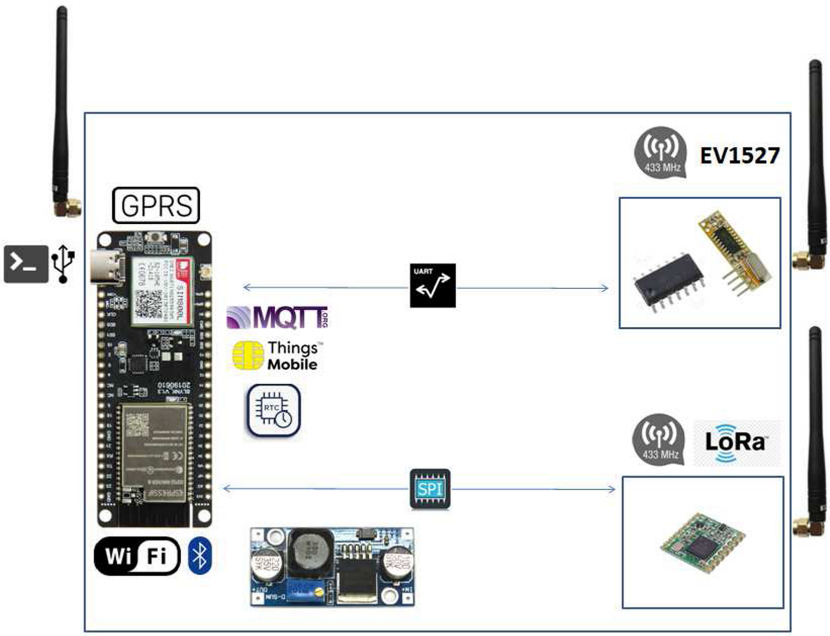

Fig. 3. Diagram of the gateway controller implemented, using only "of the shelf" IoT components.

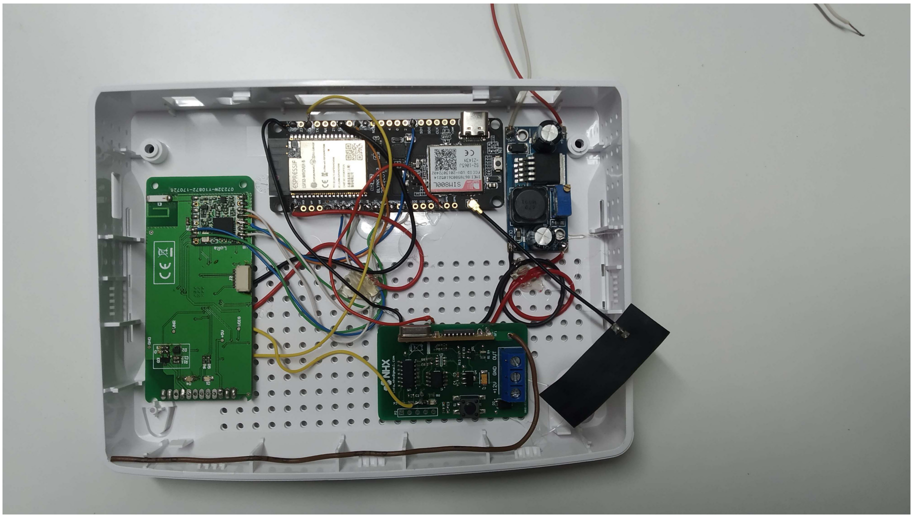

Fig. 4. Photo of the actual gateway controller implemented, using only "of the shelf" IoT components.

Fig. 5. Picture of the actual PIR activity sensor implemented, using only "of the shelf" IoT components.

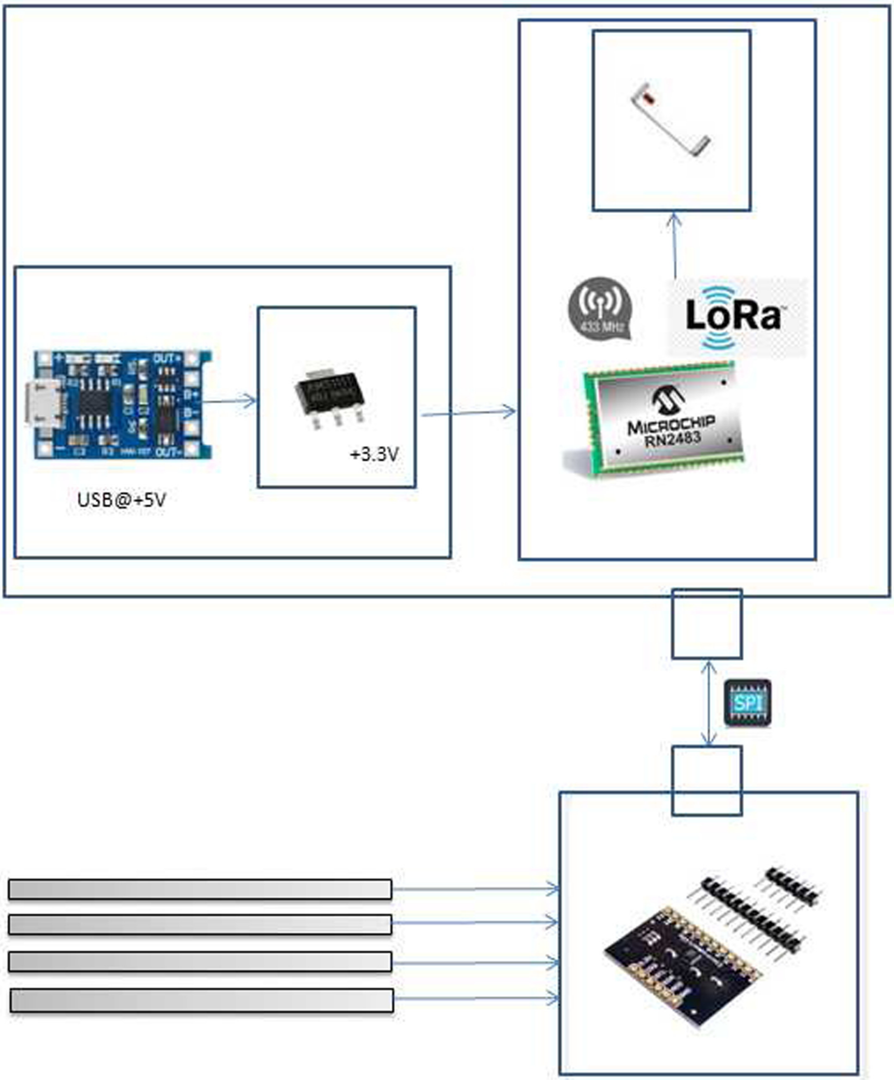

Fig. 6. Diagram of the bed activity sensor implemented, using only "of the shelf" IoT components.

Fig. 7. Photo of the actual bed activity sensor implemented, using only "of the shelf" IoT components.

For example, in Portugal it typically costs 20 € per month, whereas the price of this solution is 2 € per month. However, if the house/flat has already installed an Internet pack service, the system can use it, because the board we are using (LILYGO™ TTGO T-CALL V1.3) has already a Wi-Fi embeded module. The total cost of the IoT-based hardware used in this experiment is approximately 87 €.

As stated above, we have implemented the system depicted in Fig. 1 in a real flat, but with bedroom 2 closed, and we have tested its functioning for a week. Figures 5 presents a picture of the actual PIR sensor used, and Figs. 6 and 7 present, respectively, a diagram and a photo of the bed activity sensor implemented.

In Fig. 2 the state machine of this test-bed can be seen. The threshold alert time parameters can be configured by the caregiver, in real time, using the mobile application.

Figure 8 shows a screen-shot of the mobile application page where the caregiver can see that the system is online", meaning it is working properly, Fig. 9 shows a screen-shot of the mobile application page where the caregiver can see the latest detected activity, Fig. 10 shows a screen-shot of the mobile application page where the caregiver can see that the bed sensor was activated, and in Fig. 11 the alert SMS sent by the system.

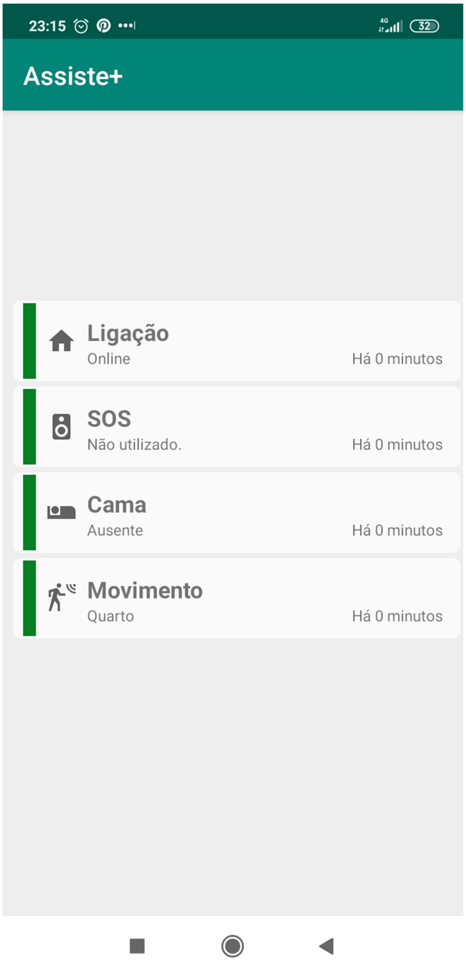

Fig. 8. Screen-shot of the mobile application page where the caregiver can see that the system "online" (working properly, first option; in Portuguese).

During the week of tests, we have monitored an elderly person's normal activity, by using a surveillance camera system, and there were no situations of false activity detections caused by the sensors (both PIR and bed sensors). Although the PIR sensors did not always detect the presence or movement of the elderly person in the room (where they are installed) at first, they always ended up detecting the presence of the elderly person following its subsequent

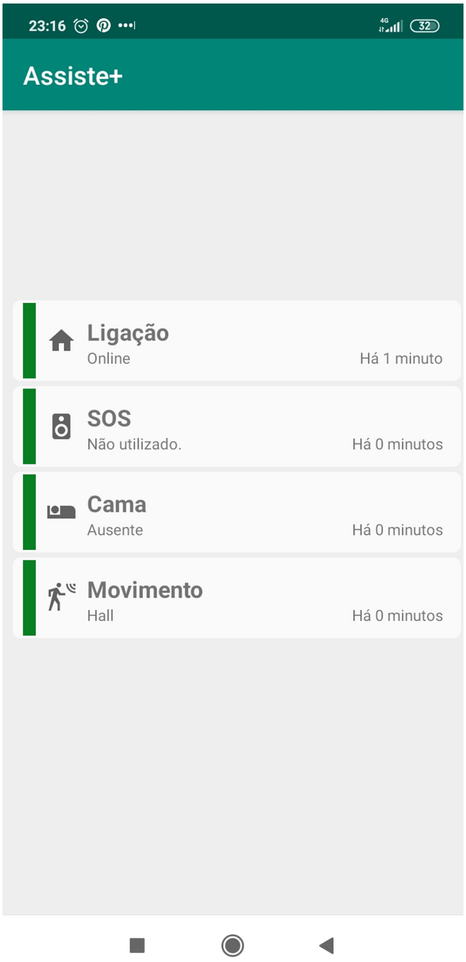

Fig. 9. Screen-shot of the mobile application page where the caregiver can see the last detected activity. In this case, it was detected movement in the "Kitchen/Dining" area (in Portuguese).

movements. This fact is not a problem for our system, since the presence of the elderly person in a given room of the house was, sooner or latter, always detected. For this reason, the number of times the PIR sensors did not detect movement at first was not counted.

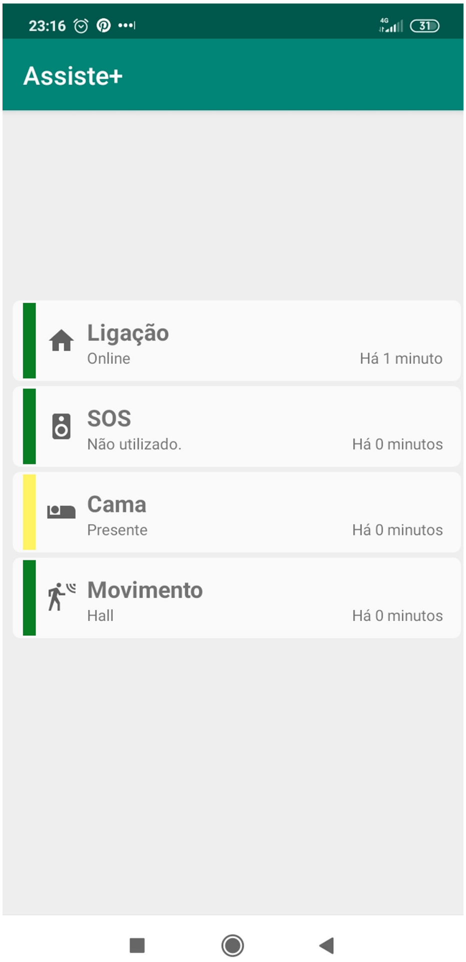

Fig. 10. Screen-shot of the mobile application page where the caregiver can see that the bed sensor was activated (in Portuguese).

The panic button was also tested and it has functioned well; fortunately, the elderly person did not have no need to use it in a real situation. In Fig. 12 we can see a screen-shot of the app where the red sign indicates that the "Panic Button" was pressed.

We have also tested the changing of the threshold alert times in real-time and no errors occurred. Additionally, all the alert SMS were correctly sent.

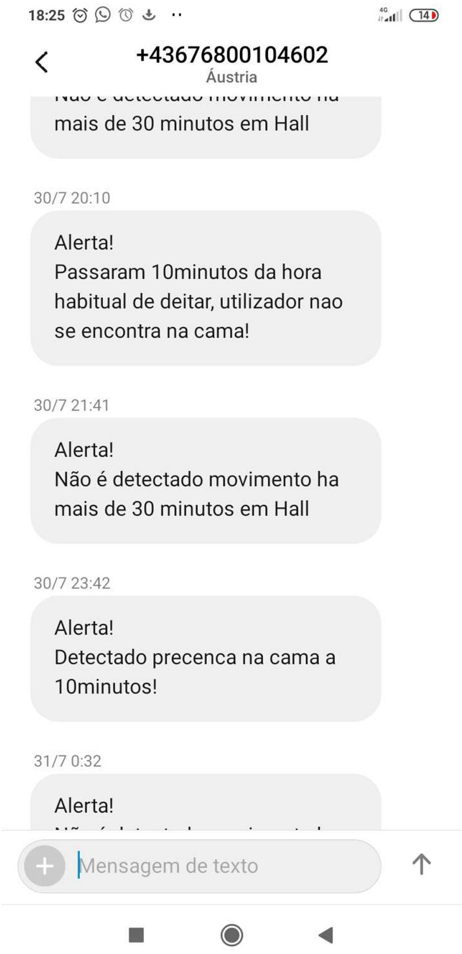

Fig. 11. Screen-shot of the mobile application page where the caregiver can read the alert SMS sent by the system (in Portuguese).

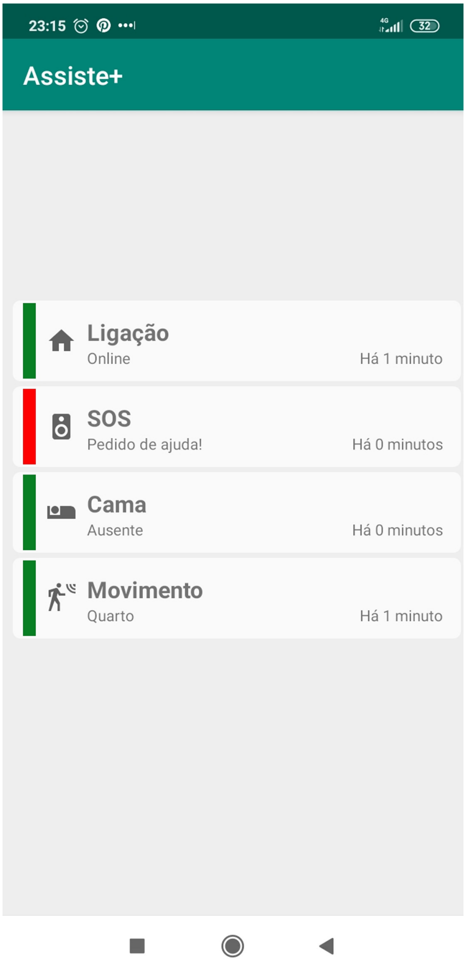

Fig. 12. Screen-shot of the mobile application page where the caregiver can see that "Panic Button" (in red) was pressed (in Portuguese).

5 Conclusions

A non-intrusive IoT-based real-time alert system for elderly people was presented. The system aims at being low-cost and made using "of the shelf" electronic components. The system is prepared to integrate other monitoring devices already available on the market, such as bracelets, video cameras, robots, among others.

The conducted tests, both laboratorial and house-hold tests, have prove the effectiveness of the system, and the system tested has a total price less than 100 €.

In the near future we want to integrate Convolutional Neural Networks (CNN) with Deep Learning algorithms in the system, in order to identify patterns of the behavior of the elderly person, and thus automatically adapt and fine-tune the individual threshold times of each state for the sending of alert SMS.

References

1. Alakhras, M., Oussalah, M., Hussein, M.: A survey of fuzzy logic in wireless localization. EURASIP J. Wirel. Commun. Netw. **2020**(1), 1–45 (2020). https://doi.org/10.1186/s13638-020-01703-7
2. Almeida, A., Mulero, R., Rametta, P., Urošević, V., Andrić, M., Patrono, L.: A critical analysis of an IoT-aware AAL system for elderlymonitoring. Future Gener. Comput. Syst. **97**, 598–619 (2019). https://doi.org/10.1016/j.future.2019.03.019. http://www.sciencedirect.com/science/article/pii/S0167739X18321769
3. Ashraf, I., Hur, S., Park, Y.: Smartphone sensor based indoor positioning: current status, opportunities, and future challenges. Electronics **9**(6) (2020). https://doi.org/10.3390/electronics9060891
4. Belmonte-Fernandez, O., Puertas-Cabedo, A., Torres-Sospedra, J., Montoliu-Colas, R., Trilles-Oliver, S.: An indoor positioning system based on wearables for ambient-assisted living. Sensors **17**(1) (2017). https://doi.org/10.3390/s17010036
5. Ciabattoni, L., et al.: Human indoor localization for AAL applications: an RSSI based approach. In: Cavallo, F., Marletta, V., Monteriù, A., Siciliano, P. (eds.) ForItAAL 2016. LNEE, vol. 426, pp. 239–250. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-54283-6_18
6. De Poorter, E., Van Haute, T., Laermans, E., Moerman, I.: Benchmarking of localization solutions: guidelines for the selection of evaluation points. AdHoc Netw. **59**, 86–96 (2017). https://doi.org/10.1016/j.adhoc.2017.02.002. http://www.sciencedirect.com/science/article/pii/S1570870517300264
7. Eisa, S., Moreira, A.: Requirements and metrics for location and tracking for ambient assisted living. In: 2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN), pp. 1–7 (2012). https://doi.org/10/ggcfbg
8. Eisa, S., Moreira, A.: A behaviour monitoring system (BMS) for ambient assisted living. Sensors **17**(9), 1946 (2017). https://doi.org/10/ggk8qb
9. Gharghan, S.K., et al.: Accurate fall detection and localization for elderly people based on neural network and energy-efficient wireless sensor network. Energies **11**(11) (2018). https://doi.org/10.3390/en11112866

10. Global Coalition on Aging: Relationship-based home care: a sustainable solution for Europe's elder care crisis. Technical report, Global Coalition on Aging, London (2018)
11. Grunerbl, A., Bahle, G., Lukowicz, P., Hanser, F.: Using indoor location to assess the state of dementia patients: results and experience report from a long term, real world study. In: 2011 Seventh International Conference on Intelligent Environments, pp. 32–39 (2011). https://doi.org/10.1109/IE.2011.22
12. Kearns, W.D., Algase, D., Moore, D.H., Ahmed, S.: Ultra wideband radio: a novel method for measuring wandering in persons with dementia. Gerontechnology **7**(1), 48 (2008). https://doi.org/10/cv526s
13. Kolakowski, J., Djaja-Josko, V., Kolakowski, M.: UWB monitoring system for AAL applications. Sensors **17**(9) (2017). https://doi.org/10.3390/s17092092
14. Kolakowski, M., Blachucki, B.: Monitoring wandering behavior of persons suffering from dementia using BLE based localization system. In: 2019 27th Telecommunications Forum (TELFOR), pp. 1–4 (2019). https://doi.org/10.1109/TELFOR48224.2019.8971136
15. Kunhoth, J., Karkar, A.G., Al-Maadeed, S., Al-Ali, A.: Indoor positioning and wayfinding systems: a survey. HCIS **10**(1), 1–41 (2020). https://doi.org/10.1186/s13673-020-00222-0
16. Liang, P., Krause, P.: Smartphone-based real-time indoor location tracking with 1-m precision. IEEE J. Biomed. Health Inf. **20**(3), 756–762 (2016). https://doi.org/10/ggcdf7
17. Lin, Q., Zhang, D., Chen, L., Ni, H., Zhou, X.: Managing elders' wandering behavior using sensors-based solutions: a survey. Int. J. Gerontol. **8**(2), 49–55 (2014). https://doi.org/10.1016/j.ijge.2013.08.007. http://www.sciencedirect.com/science/article/pii/S1873959814000295
18. Lopes, S.I., Vieira, J.M.N., Albuquerque, D.: High accuracy 3D indoor positioning using broadband ultrasonic signals. In: 2012 IEEE 11th International Conference on Trust, Security and Privacy in Computing and Communications, pp. 2008–2014 (2012)
19. Lottis, A., Heß, D., Bastert, T., Röhrig, C.: Safe@home – a wireless assistance system with integrated IEEE 802.15.4a localisation technology. In: 2013 IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS), vol. 1, pp. 461–467 (2013). https://doi.org/10/ggk9tg
20. Maheepala, M., Kouzani, A.Z., Joordens, M.A.: Light-based indoor positioning systems: a review. IEEE Sens. J. **20**(8), 3971–3995 (2020). https://doi.org/10.1109/JSEN.2020.2964380
21. Paolini, G., Masotti, D., Antoniazzi, F., Salmon Cinotti, T., Costanzo, A.: Fall detection and 3-D indoor localization by a custom RFID reader embedded in a smart e-health platform. IEEE Trans. Microwave Theory Tech. **67**(12), 5329–5339 (2019). https://doi.org/10/ggk8qn
22. Pirker, W., Katzenschlager, R.: Gait disorders in adults and the elderly. Wien Klin Wochenschr **129**, 81–95 (2017). https://doi.org/10/f9sgwd
23. Simoes, W.C.S.S., Machado, G.S., Sales, A.M.A., de Lucena, M.M., Jazdi, N., de Lucena Jr, V.F.: A review of technologies and techniques for indoor navigation systems for the visually impaired. Sensors 20(14) (2020). https://doi.org/10.3390/s20143935
24. Studenski, S., et al.: Gait speed and survival in older adults. JAMA **305**(1), 50–58 (2011). https://doi.org/10/bf94g8

25. Varadharajan, V., Tupakula, U., Karmakar, K.: Secure monitoring of patients with wandering behavior in hospital environments. IEEE Access **6**, 11523–11533 (2018). https://doi.org/10/ggcvnn
26. Wang, Z., Yang, Z., Dong, T.: A review of wearable technologies for elderly care that can accurately track indoor position, recognize physical activities and monitor vital signs in real time. Sensors **17**(2) (2017). https://doi.org/10.3390/s17020341
27. Yusif, S., Soar, J., Hafeez-Baig, A.: Older people, assistive technologies, and the barriers to adoption: a systematic review. Int. J. Med. Inf. **94**, 112–116 (2016). https://doi.org/10.1016/j.ijmedinf.2016.07.004. http://www.sciencedirect.com/science/article/pii/S1386505616301551