Low Cost Smart Homes for Elders

Gabriel Ferreira[1], Paulo Penicheiro[1], Ruben Bernardo[1], Luís Mendes[4,5], João Barroso[3], and António Pereira[1,2](✉)

[1] School of Technology and Management, Computer Science and Communication Research Center, Polytechnic Institute of Leiria, 2411-901 Leiria, Portugal
{2131218,2130628,2130664}@my.ipleiria.pt, apereira@ipleiria.pt
[2] Information and Communications Technologies Unit, INOV INESC Innovation, Delegation Office at Leiria, Leiria, Portugal
[3] INESC TEC and University of Trás-os-Montes e Alto Douro, Quinta de Prados, 5000-801 Vila Real, Portugal
jbarroso@utad.pt
[4] Instituto de Telecomunicações, Lisbon, Portugal
lmendes@ipleiria.pt
[5] School of Technology and Management, Polytechnic Institute of Leiria, 2411-901 Leiria, Portugal

Abstract. The increase in life expectancy and the consequent aging of the general population pose, nowadays, major challenges to modern societies. Most elderly people have the usual problems related to old age, like health chronic problems and sensory and cognitive impairments. Besides that, in today's modern societies, where families have less and less time to look after for their old relatives, the isolation of the elderly is a real concern and a very current problem, which is enhanced if the elders live alone. To solve or, at least, mitigate that problem, it was developed a smart home for elders that is presented and described in this paper. The developed assistive home system, which is based on available technology, can ensure the quality of life, safety and well-being of all older adults that want or desire to live in the comfort of their home, near to their friends and in their neighborhood, instead of living in elder care centers. The proposed solution can record and analyze the elders' daily routines in order to alert (e.g., e-mails or text messages) the family members and/or social agents (e.g., doctors and caregivers) whenever an unusual situation occurs or when the elder is in danger, provide real-time audio and video when necessary and some comfort features, such as, automatic lighting and temperature control. The relevant events are recorded and maintained in a cloud database, which can be accessed through a dedicated website or by an Internet of Things (IoT) Application Programming Interface (API). Although this type of solution/service is focused in the elderly population, anybody can use it. The developed solution provides comfort and safety to elders and, at the same time, an easier way of monitoring all important events.

Keywords: Ambient assisted living · Internet of Things (IoT) · Anytime anywhere · Elderlies

M. Antona and C. Stephanidis (Eds.): UAHCI 2017, Part III, LNCS 10279, pp. 507–517, 2017.
DOI: 10.1007/978-3-319-58700-4_41

1 Introduction

The term Internet of Things (IoT) was firstly used years ago by industry researchers, but only recently emerged into the mainstream public eye [1]. This new concept is used to describe the capacity of network connected equipments and devices to sense and collect different types of data and then share that information across the Internet in order to be processed and used in several applications. It is usual to find the term industrial Internet interchangeably with IoT [2], which is not the most correct since it refers primarily to commercial applications of the IoT technology in the manufacturing field, whereas the IoT covers a much wider range of applications and therefore not limited to industrial ones. Some claim that in the next decades IoT will have a paramount impact on how the society will evolve. The facts show that IoT is growing fast, gaining a vast attention from a wide range of industries, and it will be one of the most important areas of future technology [1].

A smart home is a house, apartment or other type of dwelling that uses home automation (also known as domotics) technology to monitor and control remotely and/or automatically the state of all electronic features installed in it. For example, in this type of houses, the home lighting, heating, ventilation, air conditioning, security and camera systems are all interconnected and can be controlled from any room in the home or remotely from any location in the world by using telecommunications systems and computers, tablets or smartphones. Thus, a smart home filled with connected devices (IoT devices) make the owners lives easier, more convenient and with improved comfort, security and energy efficiency [3]. In a near future, all the home comfort equipments (e.g. lighting, heating, ventilation and air conditioning), appliances (e.g. refrigerators, washers and dryers) and security and safety systems (e.g. sensors, monitors, cameras and alarm systems) will be all available remotely (through the Internet). The possibilities for smart home IoT devices are immense and can, in fact, contribute to improve immensely the quality of life of all citizens, above all the elderly.

The modern societies are facing a fast growing of aging population. Improved health and social care over recent years has increased life expectancy worldwide. Nearly 7% of the world's population is now over 65 years of age and the predictions show that older people will rise to approximately 20% by 2050 worldwide [4]. An important part of that population has health chronic conditions or diseases and lives alone, which raise concerns to the family members and respective caregivers [4]. One way to improve their comfort, security and provide a prompt help response in case of an emergency is to merge the traditional smart home with elderly assistive systems [5]. A smart home for elders besides incorporating the standard comfort equipments, smart appliances and security and safety systems should have health monitoring systems, such as, pulse, blood pressure, heart rate, fall detection devices and panic buttons. Some of these devices should be wearable in order to monitor in real-time the health status of the elderly. These devices must have versatile functions and be user-friendly in order to allow elders to perform tasks with minor intrusion and disturbance, pain, inconvenience or movement restrictions.

The type of environment provided by the smart homes for elders is based on a new paradigm of technology where people are assisted by an ambient intelligence, that is supported by a high range of data collecting and computing devices [6]. The environment collects all the necessary information about the context and presence of people and it is able to adapt to home occupants needs, habits, movements and emotions. Thus, this technology has the potential to enable people to live in their own home rather than being hospitalized or institutionalized [7]. The smart home for elders proposed in this paper presents a low cost solution of an in-home assistive system merged with a home automation system. The purpose of that is to provide to elders a pleasant way of live without the need to leave the comfort of their homes.

The rest of the paper is organized as follows. Section 2 presents some works related to the assistive home systems. The general architecture of the proposed smart home for elders is described in Sect. 3. In Sect. 4, the implementation of a functional scaled model of a smart home for elders is presented and in Sect. 5 the performance of the developed prototype is evaluated. Also, in this section, the performance of the developed prototype is evaluated. Finally, in Sect. 6, the conclusions are drawn and some ideas for future work are presented.

2 Background

The work presented by Costa et al. [6] states that ambient intelligence can transform current spaces into electronic environments that are responsive, assistive and sensitive to the human presence. Those electronic environments will be fully populated with dozens, hundreds or even thousands of connected devices that can share information and thus become intelligent. The massive deployment of electronic devices will invade everyday objects, turning them into smart entities, keeping their native features and characteristics while seamlessly promoting them to a new class of thinking and reasoning everyday objects [6].

The smart home for elderly care presented in [8], which is based on a wireless sensor network, demonstrates that ZigBee is well suited for smart homes and automation systems. ZigBee is a low cost, low power and low complexity wireless standard [8].

In [9], a smart elderly home monitoring system was designed and developed. In it, an Android-based smartphone with 3-axial accelerometer was used to detect falls of the carriers. Also, a remote panic button has implemented in the same Android-based smartphone. In this system, the smartphone uses Wi-Fi to connect to the TCP/IP network in order to access to the monitoring system. The developed system allows elderly and chronically ill patients to stay independently in their own homes knowing that they are being monitored.

The work presented by Gaddam et al. [10] uses intelligent sensors with cognitive ability to implement a home monitoring system for elder care application. These used sensors can detect the usage of electrical devices, bed usage patterns and flow of water. Besides that, the system also incorporates a panic button. The cognitive sensors provide information that can be used to monitor the elderly status by detecting any abnormal pattern in their daily home activities.

The work presented by Chan et al. [11] reviews how elderly and disabled can be monitored with numerous intelligent devices. Their article presents an international selection of leading smart home projects, as well as the associated technologies of wearable/implantable monitoring systems and assistive robotics. The latter are often designed as components of the larger smart home environment.

The qualitative study presented by Courtney [12] analyzes the relationship between privacy, living environment and willingness of older adults that live in residential care facilities to adopt smart home information technologies (IT). His work was based on the data obtained through focus groups and individual interviews. The study findings indicate that privacy can be a barrier for older adults' adoption of smart home IT, however, their own perception of their need for the technology may override their privacy concerns. Privacy concerns, as a barrier to technology adoption, can be influenced by both individual and community factors.

The works presented above are significant in the area of the smart homes for elders, and the concepts reported on those works are very useful and can be used as a base reference to the characteristics definition of low cost solutions, as the one proposed and described in this paper.

3 System Architecture

The system architecture of a low cost smart home for elders must be flexible and scalable and, through the use of several technologies, should provide, at any time, the right support to the elder. The flexibility of the system architecture is important to make it easy and inexpensive to deploy the elder in-home assistive system in any type of dwelling. After a home assistive system starts to operate at a given site, the scalability of the system architecture is also important to maintain the costs at lower levels. The scalability prevents the installation of new physical infrastructures (e.g., cables and equipments) each time that is necessary to add new functionalities or to provide the assistive services to new clients located in the same site. In vertical buildings or in apartment complexes, which usually have a great number of apartments and, consequently, with many potential clients, the assistive system should cover all the common areas since, at the end, the final costs will certainly be reduced. The services provided to authorize users should be always available in each house or apartment and in the common areas of the condominiums (if applicable). Therefore, the system architecture should be thought and developed always taking into account the type of housing complex. The services that a home automation and assistive system should provide constitute another important input to the system architecture definition since different services require different technologies. The system proposed in this paper was thought to provide home automation and in-home assistive features like comfort features, such as, automatic lighting and temperature control; security and surveillance services like intrusion detection, access control, video and audio recording; detection of harmful or dangerous situations (e.g., smoke, fire, flood and toxic-gases); elder real-time monitoring (e.g. heart rate, pulse, stress level and oxygenation); emergency calls (through the use of a panic button); and other home amenities, such as, automatic irrigation (when applied). The above-mentioned services are very important to the comfort and security of elders.

The system architecture is illustrated in Fig. 1 where the network structure and its constituent parts are highlighted. The control and monitoring of the clients' residences are performed remotely through the use of the internet services. The events and alerts are all recorded in the cloud servers located in the cloud datacenter and when an emergency situation emerges the right support is immediately triggered. The system online platform will have a common managing area for the condominium and a private managing area for each home or apartment. Since important data is saved and maintained in the servers, the users can access to it through the system online platform. The clients can obtain various informations related to the solution adopted and all their configurations and data.

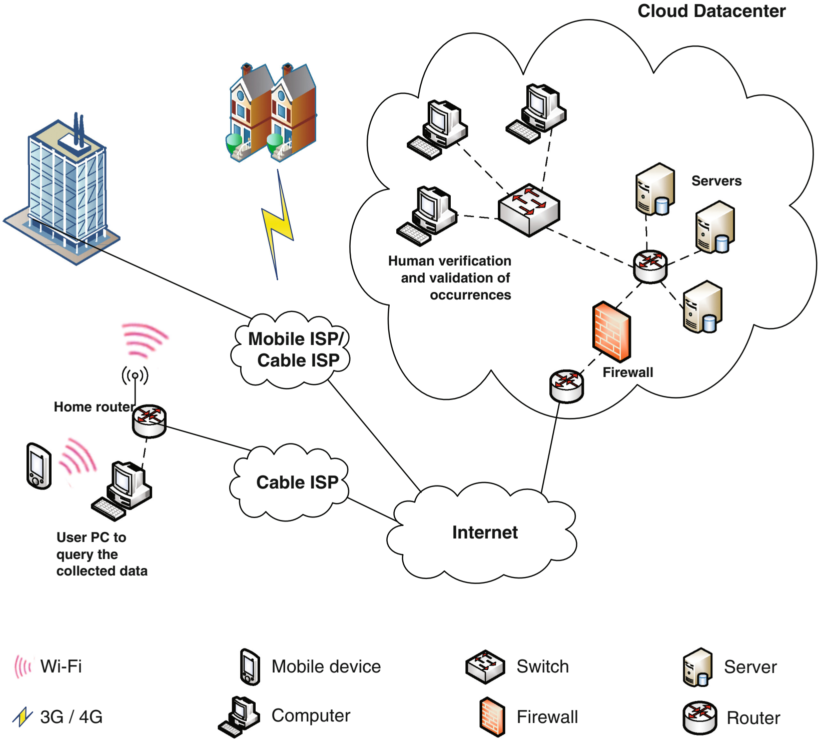

Fig. 1. Architecture of the proposed system.

Telecommunication networks are crucial to the system operation. At the house complexes, and whenever possible, communications should be performed wirelessly, using the IEEE 802.11n technology. In the situation where wireless communications are not viable, the areas should be served by copper cabling (CAT6). Common areas of the house complexes will accommodate racks with the network equipments. To connect the system deployed in the house complexes with the servers an internet service provider can be used.

Figure 2 shows the solution applied to a single-family detached home. As it can be seen, there are several sensors and actuators that are all connected to the house network. To monitor the elder in real-time, he must always use a sensory bracelet that is capable of measuring some health parameters and signals (e.g. heart rate, pulse, stress level and blood oxygen concentration) and transmit the acquired data to the platform servers if one or more health indicator suffers a significant change from the normal values. When this situation occurs an alarm is generated and the right emergency service is activated. The assistive system also supports the usage of a panic button that can be placed in a given place (e.g. near the bed) or accompany the elder. The panic button can be configured to directly call an emergency line or to establish a call to a relative of the elderly.

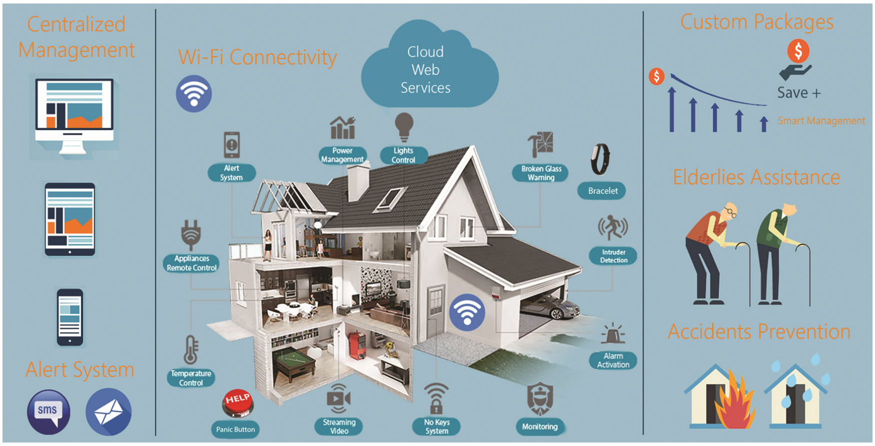

Fig. 2. Diagram of a full-integrated in-home automation and assistive system.

The home automation sensors and the assistive sensors send all the relevant information to the cloud servers to be managed and processed, as mentioned. When an abnormal situation occurs the system detects it and activates the right support services. The presented solution is the one that should be provided to elderlies that live all by themselves since it give them a better quality of life with real comfort and security.

4 Implementation

This section presents and describes the development and implementation of a functional prototype in order to demonstrate the technical and economic feasibility of the proposed home automation assistive system.

Figure 3 shows the architecture of the implemented system. In this prototype some of the functionalities presented in Sect. 3 were implemented. As it can be seen, the prototype can be divided in 3 distinct modules, namely, the comfort module, security module and the communication module. All these sub-systems are relevant to the well-being and sense of security of the elders.

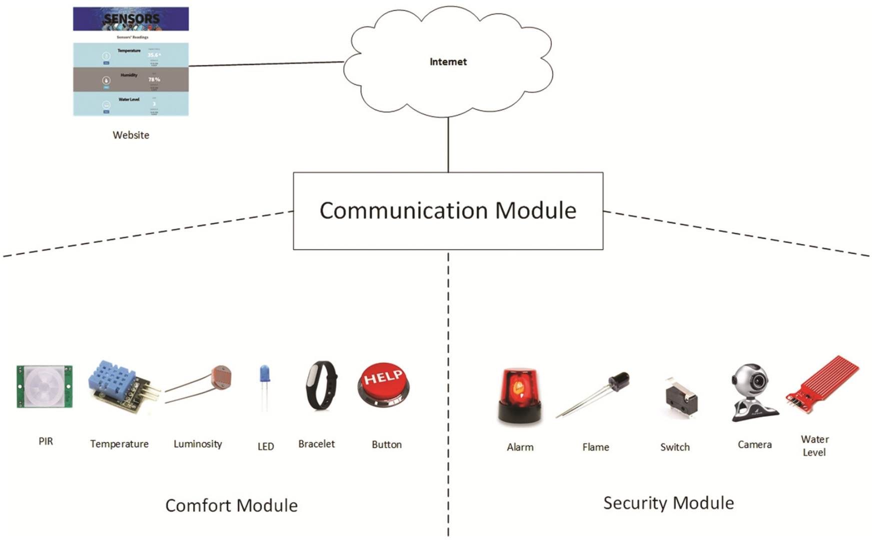

Fig. 3. Block diagram of the implemented prototype.

The implemented functions of the comfort module are the automatic lighting and the monitoring of the interior temperature and air humidity. The automatic lighting sub-system measures (light sensors) continuously the interior natural light in order to control the artificial light actuators. This system uses two thresholds of ambient light to define the light levels that must be activated. When the level one is reached, part of the illumination is activated (here simulated by LEDs) corresponding to a low artificial intensity light. When the interior natural light is really low, the second threshold is attained, and, consequently, the system activates all the available lights. The activation of the lights is also dependent of the presence of people at home.

The second feature of the comfort module is the monitoring of the temperature and humidity levels. As in the automatic lighting sub-system, the temperature and humidity are continuously monitored. The thresholds of the automatic lighting system and the levels of the interior temperature and humidity can be viewed and defined in the home managing console (tactile LCD display) or by using the web platform.

The goal of the security module is to provide the house protection and security of the home occupants. For that, it incorporates several types of sensors and, consequently, several sub-systems. To present house floods, a water level monitor sub-system, which is very useful in kitchens, bathrooms and laundries, was implemented. This sub-systems monitors the water level and when it reaches a given value, the solution activates an alarm and sends a warning to the web platform. Another security feature is the fire detection sub-system. The smart home uses a sensor that detects any kind of fire and triggers an alert and a warning to the web platform. The last security feature implemented in the prototype is the intrusion detection. Here, simple switches that simulate the magnetic doors and windows sensors were used. Every time each switch is activated, simulating an intrusion, the home control board (Raspberry Pi3 [13]) takes a picture of the place where the intrusion is taking place and send it to the web platform along with the corresponding warning. The house alarm is also turned on.

The communications module is responsible to send in real-time the information gathered by the house sensors to the web platform so that it can be managed, processed and recorded. The maintenance of the data in web servers allows the user to access it any time and everywhere. The management and control of every aspect of the system features by the client is always performed through the communications module.

In the implemented solution prototype, the main devices responsible to manage the comfort and security features are the Raspberry Pi3 [13] and the Yun [14]. To manage the security features the Raspberry Pi3 was used. Python [15] scripts with threads were used to process and send the pictures files to the web server. On the other hand, the Arduino was used to gather the sensors' information and update their information in the web platform so the users could access and visualize it. The Arduino was programmed with C language [16].

The platform website is one of the places where the clients can access and manage their information and collected data, as mentioned before. The website is structured into four main areas: Landing Page, Check Sensors, Check Security and Elderlies Care. In the website it can be found general useful informations, the procedures to monitor and control a smart home, the contacts of the service provider, emergency numbers and all the collected values of the home sensors. Since data is acquired in real-time the client can always check if something abnormal is happening. The entire site was developed using the languages HTML5 and CSS for composition and structure of the site; JavaScript and J-Query for the animations and some validations; and PHP was used to develop the scripts that gather data from sensors and the photographs, posting them to the respective areas of the website.

A photo of the implemented prototype is presented in Fig. 4. This photo shows some of the used electronic and communication boards and some sensors and actuators.

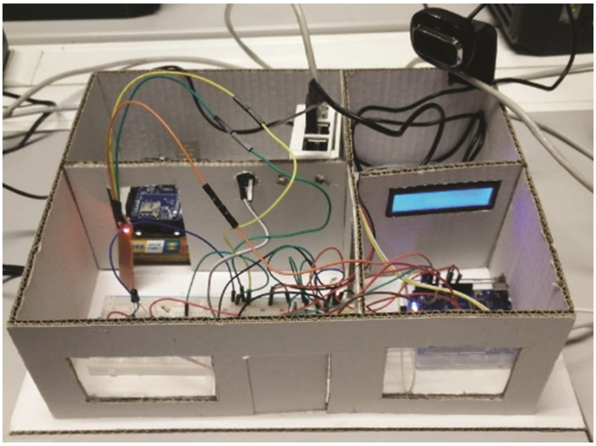

Fig. 4. Photo of the developed prototype.

Figure 5 shows the Sensor Check area of the website. As it can be seen, the sensor values are available to each client.

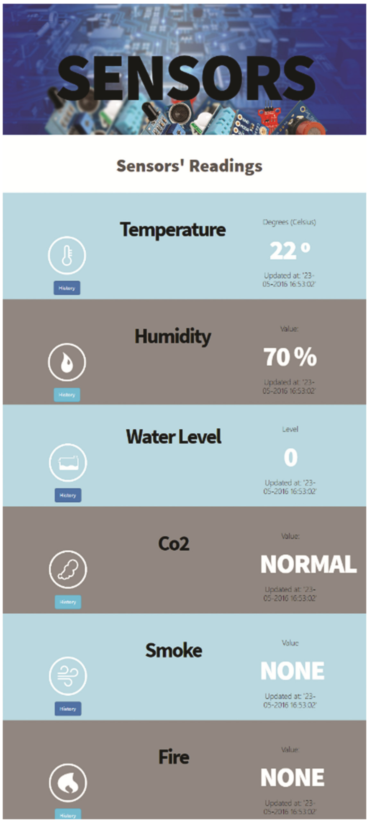

Fig. 5. Web page of the sensors information.

5 Tests Conducted to Analyze the Solution's Behavior

To assess the performance of all electronic parts (hardware and firmware) several tests were conducted. The used methodology is the following one. First, each sensor or actuator was tested independently of all the others. The information gathered by each sensor was displayed on the LCD screen. In this way, the performance was inferred by the operating status of the respective sensor. After the operation validation of all the sensors, the alarm associated to each sensor was tested. For that, abnormal situations were imposed to verify if the alarm is triggered. To simulate the alarm operation a buzzer was used. After confirming the right operation of each sensor and respective alarm, the communication with the server was evaluated.

To test the temperature and humidity monitoring sub-system, the sensors were submitted to abnormal conditions, which activate the alarm, sending its values to the

LCD display and to the website and generating a buzzer sound at the same time. For the fire detection assessment, a small flame (lighter) was approximated to the sensor to force an abnormal condition. This act caused an alarm (buzzer sound), an update of the contents of the home LCD display and the sending of an emergency message (word "FIRE") to the website. To test the flood detection sub-system, a cup of water was used. The sensor was submerged below the limit defined in the configuration script, forcing an abnormal value, which caused an alarm (buzzer sound), a new notice in the LCD display and an update of the home status in the website (the word "FLOOD" was sent). To test the intrusion detection sub-system, a simple switch was used (simulates the door or window sensor). Each time the switch was pressed, the Raspberry Pi3 [13] took a picture (through the control of a camera) and sent it to the website, also generating the respective alert. Finally, the performance of the automatic lighting sub-system was assessed simply by controlling the ambient light. The system acted accordingly with the specifications. Part of the LEDs (they simulate the real illumination) were activated when the ambient light level was maintained between the two defined thresholds and when the light were completely cut the lighting system turned all LEDs on.

6 Conclusion and Future Work

The paper proposes and describes a smart home for elders that integrate home automation systems with assistive ones in order to fulfill the elder needs. The system provides to the elder that live alone in their home the comfort and security he requires and, simultaneously, the tranquility to his family. The proposed system architecture allows the users to control anytime and from anywhere all the home features using the system app on any mobile device or through the system online platform. The elder's relatives (family members responsible for the elder) are always informed of his health and status situation and receive an alarm when abnormal situation occurs.

An operational scaled model is also presented and described in the paper in order to demonstrate the solution feasibility. Many of the proposed functionalities were implemented in the mockup house. The scaled model uses an Arduino Yun and a Raspberry Pi to control all the deployed sensors, to acquire all the sensors' data and to send it to the system cloud servers. Several functional tests that replicate daily situations were performed to assess the system. The obtained results show that the proposed solution is functional.

An important limitation of the implemented prototype is related to the cabled infrastructure. Thus, in a close future, and in order to improve the system flexibility and functionality, all the cabled parts of the infrastructure will be replaced by a wireless one. Other major feature that it will be developed and implemented in the proposed system is an ambient assisted living capable of detecting abnormal or unusual elder's behavior patterns and health problems, generating warnings or alarms to the care givers and elders' relatives. The ambient assisted living will be based on the behavior analysis algorithms that have the ability to process all the data collected from each sensor (deployed in the home and wearable).

Acknowledgements. This work was supported by Project "NanoSTIMA: Macro-to-Nano Human Sensing: Towards Integrated Multimodal Health Monitoring and Analytics/ NORTE-01-0145-FEDER-000016" financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF).

References

1. Lee, I., Lee, K.: The Internet of Things (IoT): applications, investments, and challenges for enterprises. Bus. Horiz. **58**(4), 431–440 (2015)
2. Gilchrist, A.: IIoT reference architecture. In: Gilchrist, A. (ed.) Industry 4.0, pp. 65–86. Apress, New York (2016)
3. Barlow, J., Venables, T.: Will technological innovation create the true lifetime home? Hous. Stud. **19**, 795–810 (2004). No. 907688161
4. OECD: Organisation for Economic Co-operation and Development, p. 55. OECD, Paris (2011)
5. Ni, Q., Hernando, A.B.G., de la Cruz, I.P.: The elderly's independent living in smart homes: a characterization of activities and sensing infrastructure survey to facilitate services development. Sensors (Basel) **15**(5), 11312–11362 (2015)
6. Costa, N., Domingues, P., Fdez-Riverola, F., Pereira, A.: A mobile virtual butler to bridge the gap between users and ambient assisted living: a smart home case study. Sensors (Basel) **14**(8), 14302–14329 (2014)
7. Menschner, P., et al.: Reaching into patients' homes–participatory designed AAL services. Electron. Mark. **21**(1), 63–76 (2011)
8. Ransing, R.S., Rajput, M.: Smart home for elderly care, based on wireless sensor network. In: 2015 International Conference on Nascent Technologies in the Engineering Field, pp. 1–5 (2015)
9. Lee, J.V., Chuah, Y.D., Chieng, K.T.H.: Smart elderly home monitoring system with an Android phone. Int. J. Smart Home **7**(3), 17–32 (2013)
10. Gaddam, A., Mukhopadhyay, S.C., Sen Gupta, G.: Elder care based on cognitive sensor network. IEEE Sens. J. **11**(3), 574–581 (2011)
11. Chan, M., Estève, D., Escriba, C., Campo, E.: A review of smart homes- present state and future challenges. Comput. Methods Programs Biomed. **91**(1), 55–81 (2008)
12. Courtney, K.L.: Privacy and senior willingness to adopt smart home information technology in residential care facilities. Methods Inf. Med. **47**(1), 76–81 (2008)
13. Raspberry Pi3. https://www.raspberrypi.org/products/raspberry-pi-3-model-b/. Accessed 05 Feb 2017
14. Arduino Yun. https://www.arduino.cc/en/Main/ArduinoBoardYun. Accessed 05 Feb 2017
15. Python. https://www.python.org/. Accessed 05 Feb 2017
16. Arduino Programming. https://www.arduino.cc/en/Reference/HomePage. Accessed 05 Feb 2017