Smart System for Supporting the Elderly in Home Environment

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Abstract. This work presents the development of an assistive system for the elderly in their home environment. The purpose of this system is to provide them support and extend their autonomy in order to extend life expectancy and improve quality of life when living at home. This work explores various technological innovations and technology building blocks, such as open software and open hardware. In this work, a low-cost and small-scale ubiquitous system was developed that does not disrupt the prevailing conditions in the elderly's home. Also, a part of this work has been developed, keeping in mind elderly people suffering from dementia, offering a sufferer-centered solution.

Keywords: Smart home · Assisted living · Internet of Things · Dementia

1 Introduction

Global demographic trends show that the population aging is very fast. According to the report [1], the population of the European Union in 2017 amounted to 511.5 million, of which 19.4% consisted of people over 65 years of age. The percentage of the population aged over 65 increased in all EU Member States as it rose by 0.2% compared to the corresponding 2016 and by 2.4% compared to 10 years ago.

Furthermore, dementia is a collective name for progressive brain syndromes that affect memory, thought, behavior and emotions of the elderly. Dementia is a major cause of disability and dependability for the elderly. Dementia affects about 50 million people worldwide, with a new case of dementia happening every 3 s worldwide. Until today, there is no cure for most types of dementia, but there are treatment and support [2].

Also, the desire of the elderly is to extend the time they live in their preferred environment, i.e. their home, increasing their autonomy, self-confidence, and mobility. These reasons have led the world scientific community to develop solutions for the assistive living of the elderly, as living independently in their own homes is an important goal for an increasing part of the world population.

Thus, with the help of constantly evolving technology, there have been developed solutions which mainly offer an environment that provides facilitation, like

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safety, well-being, etc., in the daily lives of the elderly. This work proposes an open software/hardware system to assist the elderly in their home environment. Its aim is the support, protection, well-being, and maintenance of their health and functional abilities, without discriminating between a sufferer of dementia or someone aging healthy. This system will consist of individual subsystems that will operate independently but will also be able to communicate with each other. The subsystems concern the safety of the elderly within the limits of their residence, prosperity, and support.

2 Exploration of Smart Homes

In recent years, a variety of home assistive systems for elderly people have been proposed. Already there are various assistive living systems, either in the experimental or research phase, which in the near future will be able to meet all the needs and requirements of the elderly for their controlled and autonomous life. For categorization reasons, we have divided the projects into two groups, those that refer to support the elderly, and those that refer to support dementia elderly people. Some of these works are presented below.

2.1 Supporting Systems for the Elderly

In [3] the proposed system oversees and helps the elderly maintain their level of physical activity balanced as well as perform their rehabilitation exercises after a serious illness in their home. A platform with various services aiming to enable older people to participate in social networks to prevent isolation and loneliness and improve their well-being is presented in [4]. An open hardware and software home-based system has been proposed in [5], which provides an integrated and easy-to-use residential system through which the elderly will have the means and technologies to have control of their lives for a longer period of time. In [6] a Personal Virtual Assistant allows the elderly to live independently for a longer period of time, with the use of assistive technology. The system at [7] aims to maintain the independence of older people by monitoring their physical state with mobile devices, assessing their neurological status using mobile phones and promoting self-care. The project in [8] provides to the elderly a set of services to organize their daily routine and monitor their health through an easy-to-use online platform. In [9] a virtual assistant is proposed to facilitate communication and cooperation between the elderly and their carers. A system that has smart internet applications to provide the elderly with personalized and environmentally-friendly help in their homes, to improve their quality of life, to be assisted whenever needed, to monitor their medication and rehabilitation physiotherapy and to reduce the cost of their health care is proposed in [10]. A proposed integrated, mobile and adaptive solution for remote sensing to support both patients, relatives, and friends with abnormal heart failure, as well as cardiologists and health professionals, in general, is presented in [11]. In [12] the development of mental health tools for the elderly and their families are presented, as well as for specialists, to measure and visualize the mental changes of the elderly.

2.2 Supporting Systems for the Elderly Focusing on Dementia

In [13], a system has been proposed to monitor the activities of dementia people, using sensors, to maintain their autonomy and quality of life, to provide them with a sense of security at home and to delay, as much as possible, their hospitalization in a care center for dementia people. A platform that allows remote monitoring and personalized intervention and care of the dementia people in order to support and maintain their health and functional and cognitive abilities is presented in [14]. In [15], various devices have been developed to support sufferers and their carers, such as memory support devices (e.g. medication reminders, etc.), devices that provide entertainment, and devices to facilitate communication (e.g. pre-programmed telephone). A service that supports the increase of the independence and well-being of dementia sufferers in their home environment, and reduces their social isolation, increases their participation in their daily activities, stimulate their cognitive skills and access to Internet services, is presented in [16]. Another innovative tool for supporting people with mild dementia for the provision of remote care, which exploits the transmission of data via television and the interplay of video between health professionals, sufferers, carers and sufferers' families using the Internet is presented in [17]. In [18] is presented a complete solution for the care, treatment, and diagnosis for dementia sufferers, which motivates them to perform personalized, emotionally oriented exercises, to stimulate cognitive processes, to cope with physical activities and promoting their social inclusion. The system in [19] helps dementia people in their daily routine, creating a room atmosphere that supports their feelings, activity, and mood. It consists of light, sounds and smells so that the atmosphere of the room is shaped to improve the mood and behavior of both the sufferers and the caregivers. The room's atmosphere creation is achieved by checking the calculated data of the people involved in their daily routine. A platform to monitor the movements of dementia people indoors and outdoors to identify them, to satisfy the desire of their relatives to monitor the location of the sufferers in order to avoid situations of danger, and to provide information when they leave a particular area, such as their home, hospital, etc. has been proposed in [20]. A platform capable of monitoring the behavior of users (movements, speech, interactions) and supporting individualized control of lights and devices in their environment, is presented in [21]. This project aims to help people with mild dementia to stay oriented at what they are supposed to do, by providing intelligent support capable of controlling devices in such a way as to flexibly drive their attention and behavior towards their goals.

2.3 Commercial Smart Home Solutions

There exist nowadays commercial smart home solutions covering partially the needs of elderly people. They mainly focus on safety and security services, however, some of the systems intervene in the elders home, disrupting their day-to-day life, or require extensive training, while others cost a few hundred dollars for installation and operation. Selected promising and well established smart home solutions are presented below.

The smart home system in [22] provides safety and security services like smart locks that sends alerts to the cell phone when a door opens, indoor cameras for two-way communication, doorbell cameras that permit the home's residents to check and respond to a person at the door either they are at home or not, and thermostats that adjust automatically home temperature to the preferences of the home's residents. The control of smart devices via voice and an application for smartphones and tablets for remote control is offered in [23]. In this way, the system can provide monitoring, warnings, safety, and security to the elders. The commercial solution in [24] provides elderly people remote control on heating, remote monitoring of their home, measurement of the indoor and outdoor conditions of the home environment. In parallel, the system allows optimization of their comfort and well-being at home, via smart devices in their house like smart thermostats, smart door and window sensors, a smart video doorbell, etc. In [25] smart home services via different kinds of sensors and actuators that set up at home are provided. These services are the focus on safety, security, and improvement of the elderly's well-being. Different kinds of services, via actuators and embedded systems, provide to older people the remote control of the home's lighting, blinds, switches, heating, and cameras in [26].

The main characteristic of the previously mentioned systems is the high cost, which is a significant issue for the elderly people. Furthermore, although the systems are based on high technology, it is not open and available to others. This affects not only the cost but also the availability worldwide.

3 Proposed System

This work aims at proposing an elderly care system for use in their home environment to support, protect, prosper and maintain their health and functional abilities, based on open technologies. According to [27] the main needs of elderly people are safety and well-being at their homes and their support of their daily life routine. The contribution of the proposed system is to assist the needs of either the older people in general or specifically the older people suffering from dementia, with the use of low-cost and small-scale Information and Communication Technologies (ICT) solutions. Thus, this system will consist of autonomous subsystems that will operate independently but will also be able to communicate with each other. The subsystems that make up the main system are three: *the safety subsystem*, *the subsystem of well-being*, and *the support subsystem*.

3.1 The Safety Subsystem

The purpose of the safety subsystem is to detect the movements of the elderly within their home space. In order to achieve this, sensors can be placed in specific locations within the house to detect any activity - movement of the elderly. Thus, in the absence of movement sense of the person for a certain period, the subsystem undertakes to communicate with the elderly.

The communication between the subsystem and the elderly will be achieved using smart speakers within the house. Thus, communication is performed via physical language and doesn't require extra training. Through smart speakers, the subsystem will ask the elderly specific and predetermined questions about his/her state of health. If the elderly respond, with a predefined response for the subsystem, that he/she is well, then the subsystem does not perform any action. If the elderly respond, with a predefined response for the system that he/she is not well in his/her health, or does not respond at all, then the subsystem will undertake to inform his/her relatives that something has happened to him/her.

Furthermore, in order to avoid false alarms from the subsystem, during installation, a categorization of the house rooms will be performed in terms of a safe place and potentially dangerous room. For example, motion sensors may not record some movement for a long time in a room classified as 'low risk', such as a bedroom. A fact that will lead the subsystem not to alert the elderly's relatives, as it is most likely to, he/she was lying down. On the other hand, if motion sensors did not record any movement in a home area characterized as 'high risk', such as the bathroom, then the subsystem will immediately update his/her relatives.

In addition, sensors will be placed at the entrances of the house in order to inform the relatives that the elderly person has gone out of the 'limits' of the house (geofencing) so that it can be traced promptly and directly by his relatives (geolocation). While the elderly will carry on a wearable device that will act as a panic button, to call his/her family immediately in case of an emergency.

In the context of the present work, only the typical infrastructure and basic functions of the subsystem were implemented, such as the infrastructure of geofencing and geolocation for the elderly. Details of their implementation are offered at the next Section.

3.2 The Well-Being Subsystem

The purpose of the well-being subsystem is to provide confidence and instill a sense of safety to the elderly, but also their relatives. This is accomplished with the placement of specific sensors at critical points into the home, as well as the use of wearable devices that the elderly will bear on them.

The wearable devices for the elderly will provide information about their location (geographic location). These devices will help to make easy and accurate the localization of the elderly if they are away from their home and are searched for by their relatives.

The location of the sensors was selected to be the kitchen and the bathroom, based on high risk categorization, for easy management of the electrical appliances and the faucets. In particular, sensors will be placed to detect whether a cooker has been left switched on, without having a pot on it or even having a superheated utensil that has been forgotten on it. In this case, the subsystem will either be able to alert the home's owners that a device remains unnecessarily switched on or even shut down the cooker. A similar case will also happen with home faucets. If a faucet is left switched on for no reason, the subsystem will either alert the occupants of the house or switch off the faucet itself.

3.3 The Support Subsystem

The objectives of the support subsystem are two; the first is to remind the elderly to receive their medication, and the second is the recognition of their familiars, in case of the elderly suffer from dementia.

The reminder of receiving the medication of the elderly will be achieved by using a device that will be adjusted according to the needs of the older people and will reproduce a distinctive sound at the time of day that medications should be taken.

The recognition of familiar people from the elderly who suffer from dementia is achieved through a specially designed infrastructure that focuses on the sufferer and uses the sound stimuli, that we have proposed in [28]. In particular, its function is to reproduce characteristic sounds for each of the familiar faces of the elderly sufferer, so that the sounds help him/her recognize more easily who is the favorite person that has entered his/her home. The reproduction of the characteristic sound for each of the familiar faces of the elderly is done by using smart speakers, that located in the elderly's home, and an identifying wearable device that will bring upon it every familiar face of the elderly. The identifying wearable device acts as the unique identifier for each familiar. Thus, whenever one of the familiar faces of older person enters his/her home, the identification device will be recognized by the smart speaker. In effect, this will reproduce the corresponding characteristic sound for that person, which will act as stimuli for the elderly who suffers from dementia, to recognize his/her beloved people.

4 Implementation

In the implementation of the proposed system, we initially implemented the basic infrastructure of each subsystem, as we wanted to keep the cost and complexity of the entire system at low levels. The basic infrastructure of each subsystem is detailed below.

4.1 The Safety Subsystem

The safety subsystem consists of two devices. The first device (D1) is the one that is installed at the home of the elderly and checks to detect the old people or not at their home. While the second device (D2) is the wearable device that the elderly bear on, so that it can be located by D1. The device D1 searches for D2 at regular intervals to create communication between them. When D2 is not detected by D1, i.e. it is out of its range, D1 generates a warning.

Both subsystem's devices were implemented with the use of special-purpose hardware, namely Raspberry Pi micro-computers. For the device D1, a Raspberry Pi 3 B+ micro-computer was used because of its programming capabilities, its operating system availability and its built-in communication protocols. While for the device D2 a Raspberry Pi Zero W was used, due to its small size and features, such as programming and operating system availability, wireless LAN connection and Bluetooth.

The communication between the two devices is achieved by using Bluetooth communication protocol, while the recognition of device D2 by D1 is achieved based on the unique MAC address identifier of each device. In the case that D1 pairs with the device D2, then it does not perform any action. Otherwise, it sends a message that the D2 device, and hence the elderly who bears it on, is not in the house.

4.2 The Well-Being Subsystem

The subsystem of well-being also consists of two devices. The device D3 is designed to monitor and control the environmental conditions prevailing in the elderly's home, by using temperature, humidity, and gas leakage sensors in the home. While, the device D4 oversees the cooker hobs if a hob has been forgotten in operation, using a sensor that provides information about the temperature of the object that supervises.

For the implementation of both devices of the well-being subsystem, the Arduino Uno was selected, an open software/hardware board, to which the sensors were connected to collect the measurements/environmental data. The sensors selected for D3 and D4 device, measure, at regular intervals, specific environmental characteristics, that often refer to critical situations that lead to accidents. Humidity and temperature are metrics that affect the quality of living in their home, while gas is associated with various reports of elderly deaths from fumes or gas leakage. Finally, frequent is the case of failure or omission to switch off cooker hobs, leading to a fire. Thus, for the device D3, a sensor is used, which measures the temperature and humidity of the environment, and a sensor for detecting leakage of natural gas and carbon gas in the room, as shown in Fig. 1. While in Fig. 2, the D4 device is using an IR temperature sensor for remotely measuring the surface temperature of a target object, while it also measures the average ambient temperature.

The communication with the central system and the transmission of the collected data was selected to implements via a wireless channel, in order to reduce the complexity of connection and to make the system safe (i.e. allow it to be used for example in the kitchen where no exposed cables are allowed). The Bluetooth HC-05 unit was selected, for the wireless communication and transmission of the device's data to the rest of the system. The transmission of data follows a structured information packet format, exploiting JSON messages. Each device initially transmits its identifier allowing information parsing to be made easily, and then the fields, as well as the values, of the measurable metrics. For example, {*id: 1, temp: 25.0, humidity: 56.5, gas: 0 leak: no leak*}.

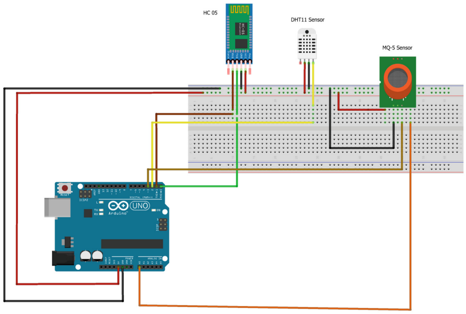

Fig. 1. Schematic representation of the D3 device.

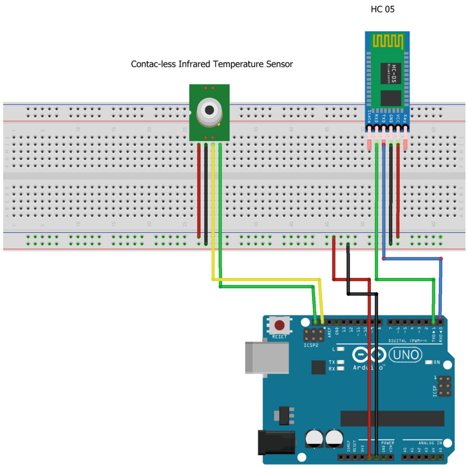

Fig. 2. Schematic representation of the D4 device.

4.3 The Support Subsystem

The support subsystem is an information system at home to support elderly people with dementia and their relatives. The information system consists of two main applications: the client application, and the server application.

The client application runs on the identifying device of the individuals (e.g. smartphone). Communication is achieved via Bluetooth with the server. At the server, the collected ID is matched to a predefined sound. Then, the corresponding sound is reproduced, which will act as a stimulus for the sufferer to recognize his/her beloved person. The identification of each device, that leads to the recognition of the right person and eventually the reproduction of the right sound, is achieved through the unique MAC address that has each device and transmits to the server.

The server application is embedded in a micro-computer Raspberry Pi 3 B+ model, which acts as a smart speaker at the patient's home. The role of the server is to handle communication with identifying devices. In addition, the server has a list of all identifying devices and their corresponding sound, which we can modify whenever necessary. So, the server searches for identifying devices, via the unique MAC address that has each device, at regular intervals to create communication between them, via Bluetooth. When the in-between communication is achieved, the server application is searching in the sounds' list for the associated sound with that device, and reproduce it.

5 Results

In this section, the functionality of the implemented system is tested and evaluated. Specifically, for the evaluation of the proper functionality of the system, experimental tests were carried out for each subsystem separately.

5.1 The Safety Subsystem

The experiments conducted for the safety subsystem concerned the ability of the device D1 to search for and locate the device D2 when the second device was in the range of the first. The tests of the safety subsystem were carried out in various rooms of a building, in order to study all possible distances between the two devices (different rooms, different floors, etc.). The test results are presented in Table 1.

Table 1. Safety subsystem tests results.

Test	Tracking the device D2	Distance of devices
1	Yes	3.7 m
2	Yes	5.2 m
3	No	19.5 m
4	No	13.0 m
5	Yes	1.9 m
6	Yes	3.1 m
7	No	2.1 m
8	Yes	3.0 m
9	No	13.9 m
10	No	16.3 m

The first six tests, as shown in Table 1, were carried out with both devices (D1 and D2) on the same floor of the building, while the remaining 4 tests were conducted with the device D1 being located on the first floor and the device D2 on the ground floor of the building. This also explains the result of test 7 against the tests 1 and 2, in which although the distance is shorter, the device D2 is not detected by D1 due to the difference in the floor. On the other hand, in test 8, although the floor difference continued to exist, the two devices were almost one below the other, so D2 was able to be identified by D1. Note that the device D1 throughout the tests was located at a specific point in the building, while the device D2 was the one that constantly changed its position. Finally, the distance between the two devices in each test was calculated using the GPS, taking in each test the different coordinates of D2, since the coordinates of D1 remained constant.

5.2 The Well-Being Subsystem

The experiments conducted for the well-being subsystem aimed to evaluate the D3 device to monitor the environmental conditions of a room (humidity and temperature). While the device D4 has been evaluated for its ability to detect the different temperatures of a cooker in operation, when there is a pot on it or when it does not, but the cooker is still in operation.

For the experiments of the D3 device, the device was placed in a room to measure the prevailing conditions of temperature, humidity and gas leakage for 1 h. Every 15 min, we affected the room conditions, near the sensor, to evaluate and validate the value fluctuations in the measurements. The measurements, lasting 1 h, took place for 5 days in 2 different rooms of a house. The results of the measurement values of the temperature are depicted in the graph in Fig. 3, the measurement values of the humidity are shown in the graph in Fig. 4, and the measurement values of the gas leakage are offered in the graph in Fig. 5.

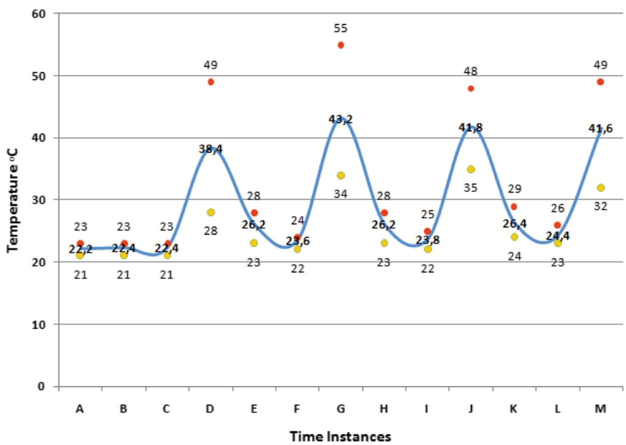

Fig. 3. Results of the measurements of the temperature of the D3 device; the blue line in the graph shows the average value of the temperature of the total measurements of the experiments, the red dots correspond to the maximum values of the temperature and the yellow ones to the minimum. (Color figure online)

Every time instance in the graph $(A–M)$ corresponds to 5 min, with A being the minute 0 and the M the 60^{th} min for each measurement. The blue line in the graph shows the average value of the temperature of the total measurements of the experiments, while the red dots correspond to the maximum values of the temperature and the yellow ones to the minimum.

At the *Time instances D, G, J, and M* we notice an increase in the temperature values, as they correspond to the 15^{th}, 30^{th}, 45^{th} and 60^{th} min, respectively, during which we affected the temperature.

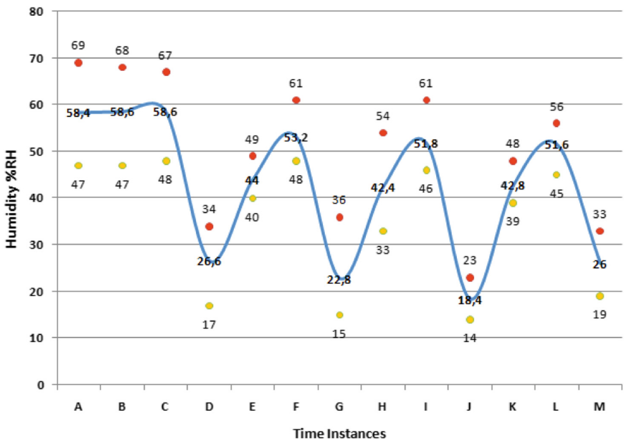

Fig. 4. Results of the measurements of the humidity of the D3 device; the blue line in the graph shows the average value of the humidity of the total measurements of the experiments, the red dots correspond to the maximum values of the humidity and the yellow ones to the minimum. (Color figure online)

As in the temperature graph, thus and in the humidity graph, every time instance in the graph $(A–M)$ corresponds to 5 min. The blue line in the graph shows the average value of the humidity of the total measurements of the experiments, while the red dots correspond to the maximum values of the humidity and the yellow ones to the minimum.

At the *Time instances D, G, J, and M* we notice a decrease in the humidity values, as they correspond to the 15^{th}, 30^{th}, 45^{th} and 60^{th} min, respectively, during which we affected the humidity.

As in the temperature and humidity graphs, thus and in the gas leakage graph, every Time instance in the graph $(A–M)$. The blue line in the graph shows the average value of the gas leakage of the total measurements of the experiments, while the red dots correspond to the maximum values of the gas leakage and the yellow ones to the minimum.

At the *Time instances A, B, C, E, F, H, I, K, and L* the gas value is 0, as there is no gas leakage in the room. While, at the *Time instances D, G, J, and*

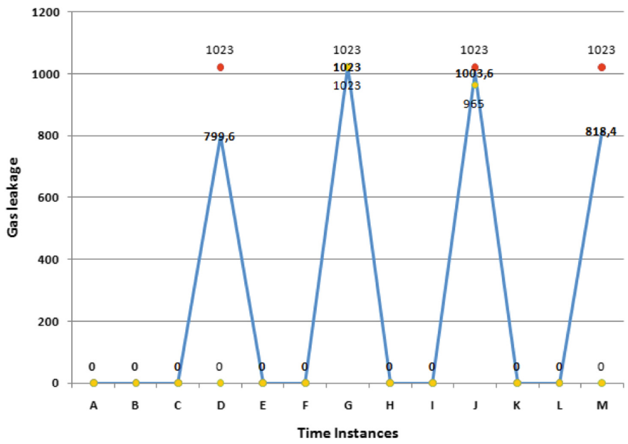

Fig. 5. Results of the measurements of the gas leakage of the D3 device; the blue line in the graph shows the average value of the gas leakage of the total measurements of the experiments, the red dots correspond to the maximum values of the gas leakage and the yellow ones to the minimum. (Color figure online)

M we notice an increase in the gas value, as they correspond to the 15^{th}, 30^{th}, 45^{th} and 60^{th} min, respectively, during which we affected the gas leakage.

The results of the measurements values of the D4 device are shown in the graph in Fig. 6. The blue line in the graph shows the average value of the total measurements of the experiments of the temperature of the object that was monitored (e.g. cooker hob and pot), while the red dots correspond to the maximum values of the temperature and the yellow ones to the minimum.

For the experiments of the D4 device, we placed the device over the cooker hobs at the height of the cooker hood, focusing on a particular hob, supervising it for 21 min, for 5 days. During the 21 min, a number of actions were carried out, such as placing a pot with water in the cooker, removing the pot with the hob remaining in operation, etc. The time duration between each action (*Time instances*) lasted a fixed time for all experiments to facilitate experiments.

Specifically, at the *Time instance A* was put the pot with water in the hob and was turned it on. After 3 min (*Time instance B and C*), we added another cold water to the pot. The value at *Time instance B* is the temperature of the pot with the water just before putting cold water, while the value at *Time instance C* is the temperature of the utensil after the cold water has been placed. At the *Time instance D*, we have measured the temperature of the pot as it continues to stay above the hob. After 3 min (*Time instance E and F*) was removed the pot from the hob, while the cooker remains lit. The value at *Time instance E* is the temperature of the pot just before removing it from the hob, while the value at *Time instance F* is the temperature of the lit hob immediately after the pot has been removed. Three minutes later (*Time instance G and H*) the pot was put back in the hob with the value at the *Time instance G* being the temperature

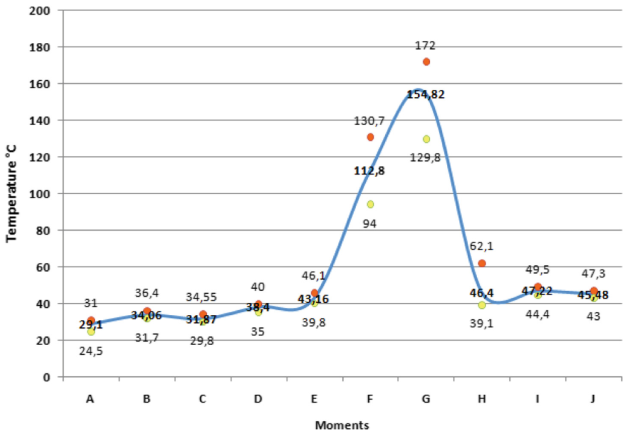

Fig. 6. Results of the measurements of the D4 device; the blue line in the graph shows the average value of the total measurements of the experiments of the temperature of the object that was monitored (e.g. cooker hob and pot), while the red dots correspond to the maximum values of the temperature and the yellow ones to the minimum. (Color figure online)

of the hob shortly before placing the utensil, while the value at *Time instance H* is the temperature of the utensil that was just put again. After 3 min (*Time instance I*), was turned off the hob while the pot stays on it. While 6 min later (*Time instance H*), were measured the temperature of the pot for the last time.

5.3 The Support Subsystem

The experiments conducted for the support subsystem aimed to evaluate-validate the identification of the client from the server, as well as the successful reproduction of the sound by the server.

In total, 20 different tests were performed. In particular, two series of 10 trials were conducted, in which two *Familiars* were examined to assess the Familiar's identity in a room and a patient. The difference between the two test groups was the device that each *Familiar* carried with. In both series, the identifier was a smartphone. While the tests were done within the limits of a room, thus the support subsystem would be located in every room of the elderly home.

The first 10 tests in the Table 2 correspond to *Familiar 1*, while the other 10 in *Familiar 2*. Both *Familiars* had a 100% success rate in their identification from the system, while in the sound reproduction *Familiar 1* had an 80% success rate since in *Test 1* was not reproduced the characteristic sound, while *Familiar 2* had a 100% success rate.

Table 2. Support subsystem tests results.

Test	Identification of the client	Reproduction of the sound
1	Yes	No
2	Yes	Yes
3	Yes	Yes
4	Yes	Yes
5	Yes	Yes
6	Yes	Yes
7	Yes	Yes
8	Yes	Yes
9	Yes	Yes
10	Yes	Yes
11	Yes	Yes
12	Yes	Yes
13	Yes	Yes
14	Yes	Yes
15	Yes	Yes
16	Yes	Yes
17	Yes	Yes
18	Yes	Yes
19	Yes	Yes
20	Yes	Yes

6 Conclusion

In this paper, a smart home supporting system for elderly people is proposed, based on low-cost building blocks, such as open software and open hardware. The aim is the protection of the elderly life, the enhancement of life quality and assistance to day-life activities, which however have a critical character. A collection of smart installments was proposed for achieving three goals, namely safety at home, smart home support and well-being. In this work, a significant part of smart sensors and devices of the proposed system are considered and implemented.

The experimental results showed that this system can offer integrated assistance for the elderly at home. The integrated assistance, in combination with the low-cost and the small-scale of the system, gives it a lead over other similar proposed systems.

As future work, the rest of the proposed system will be implemented. Also, for the safety subsystem, the aim is to include bio-metrics algorithms to take into account behavioral characteristics. While in the support subsystem the aim is the integration of the solution using smart speakers. Furthermore, as future work, the authors wish to evaluate the system's effectiveness in real conditions.

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