An IoT-Based Healthcare Ecosystem for Home Intelligent Assistant Services in Smart Homes

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Abstract. Home Intelligent Assistants (HIAs) typically integrate several types of healthcare and well-being solutions that include mobile applications, sensors or wearables. These solutions are usually connected to the HIA through the Internet designing an Internet of Things (IoT) ecosystem. This paper presents an IoT healthcare ecosystem for smart home environments that considers both indoor and outdoor scenarios. The main goal is to monitor in a pervasive way habitant vital signs, such as heart rate, temperature, and respiration, while sleeping or any other indoor and outdoor activity. A breast sensor band and smartwatch were used as wearable sensors of the ecosystem. Furthermore, smartphones and tablets were used has interfaces of the HIA. The service-oriented architecture that integrates all the IoT solutions was constructed and a secure authentication model was implemented to maintain health data privacy. This framework's main goal is to allow the integration of other IoT-based solutions regardless of its hardware or software. The proposed ecosystem and integrated solutions were validated both in terms of features and communication through a series of experiments on real devices through a Wi-Fi network.

Keywords: Health · Mobile health · IoT · Health IoT · Smart home

1 Introduction

With the advent of the Internet of Things (IoT) paradigm new and pervasive communication scenarios arose, creating new business and research opportunities. IoT includes and enables interconnected computers, machines, sensors, other objects and people, each with a unique identifier to transmit information to a network without the need for human interaction. The number of devices capable of being part of one of these systems is increasing, and as a result more and more projects focused on services or applications have been created in order to monitor, using sensors, patients health data that can be used, stored and transmitted to other devices and systems [1, 2]. IoT empowers new types of services that can benefit users in both professional and personal lives. Services, such as, manufacturing [3], transports and logistics [4], healthcare [5], Smart Cities [6],

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and Smart Homes [7, 8] are examples of field on which IoT is already creating new research and/or business opportunities. IoT is already having a great impact on the health industry. When connected to the Internet, common medical devices can collect and share great amounts of data, enabling a broader view of symptoms, and the possibility of doctors' remote care. IoT devices can help professionals to monitor several health statuses, these technologies include, for example, glucose monitoring pills, connected inhalers to help with diseases such as asthma or diabetes, ingestible sensors. These devices, coupled with a powerful monitoring platform, can certainly improve patients' health and change the way health is currently managed.

Health IoT-based solutions are becoming popular in a healthcare system that is failing all around the world and is already unsustainable. With the growth of the elderly population who spend most of their time at home, there is an urgent need for low-cost and sustainable healthcare solutions. One solution is to transform the normal home into a ubiquitous computing technology environment that supports the care and well-being of the elderly living independently. These home systems are called smart homes and are currently a hot research topic [9]. This concept involves the use of technology to ensure more comfort and safety. The first step to home automation is an Internet system. IoT networks and Smart Homes are undoubtedly unseparated. The network is responsible for connecting all smart devices, usually to Home Intelligent Assistants (HIAs) that integrate several types of devices that include mobile applications, sensors or wearables. Wi-Fi and Bluetooth are the best-known home networking technologies, but they won't always be the most efficient. Wi-Fi consumes too much power, and Bluetooth can only be used in small places. Although the great potential, IoT networking, and smart home environments raise critical challenges such as security, data value but mainly interoperability [10, 11].

This paper presents an IoT healthcare ecosystem for smart home environments. This work main goal is to present a framework for real-time monitoring, that allows the integration of both indoor and outdoor solutions, through a service-oriented architecture, called HIAS. This ecosystem includes two IoT-based solutions. The indoor solution monitors heart rate and respiration while sleeping or resting on a couch through a breast sensor band. The outdoor solutions react to emergency scenarios and monitors in real-time the heart rate, temperature and location of the user through a smartphone and a smartwatch. The HIA service-oriented architecture that integrates all the IoT solutions has also a secure authentication model that was specifically implemented for these scenarios to maintain health data privacy. This work aims to resolve both security and interoperability issues, that are common on these networks and solutions. The HIAS was already designed thinking on interoperability and the presented solutions were constructed for different users, scenarios, and environments. For this first version of the IoT ecosystem, the presented cloud architecture and integrated solutions were validated through a series of experiments on real devices through a Wi-Fi network. The proposed IoT ecosystem for both indoor and outdoor scenarios is presented in Fig. 1. It includes the following applications:

- A HIAS application that integrates all functionalities and respective interfaces.
- A mobile application for a smartwatch that collects in real-time user health data, such as, heart rate and temperature.

- A mobile application for smartphones that allows a user to initiate an emergency wi-fi call or warning to healthcare professionals or familiars through the HIAS services.
- A web application that receives a wi-fi call from the emergency mobile application. This web solution includes geo-location in real-time and voice recognition algorithms.
- A mobile application that collects health data from wearable sensors, specifically a chest band, and forwards it to the HIAS server.

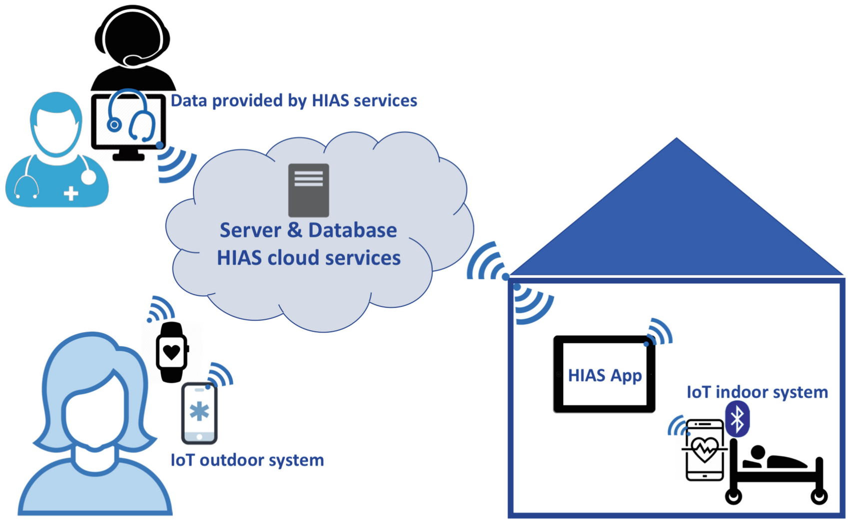

Fig. 1. System architecture of the proposed IoT-based healthcare ecosystem for home intelligent assistant services in smart homes

The remainder of this paper is organized as follows. Section 2 presents a review of the related work in both healthcare IoT and smart home solutions. In Sect. 3, the IoT healthcare ecosystem cloud architecture is presented its security mechanisms. Section 4 presents the indoor solution and its implementation details. The construction and implementation of the IoT outdoor solution are presented in Sect. 5. Finally, the paper is concluded in Sect. 6 and future work is presented.

2 Related Work

IoT solutions can provide several advantages to services provided by the health industry. On the one hand, the use of sensors allows health providers to monitor the patient's vital signs and the use of smart devices can help to transmit that information across medical facilities [12, 13]. On the other hand, IoT may support health providers by reducing various monotonous tasks and/or to enable alerts in case of emergency [14]. The CareAngel platform [15] provides a service to, remotely, monitor the health condition of elderly people. This is achieved through the use of artificial intelligence and speech recognition. The service allows his users to do daily calls to a virtual assistant, where some information about their condition is collected. This information is then shared with the authorized agents like family members or health providers. Several clinics and hospitals already use this innovative platform, however, there are some limitations associated with it, especially the resistance to change from pen-and-paper to digital technology. Apple Watch Healthcare [16] is another service integrated into a smartwatch device and uses sensors to monitor his user's heart health. Afterward, these data are processed aiming to provide valuable information about the user's condition and to emit alerts whenever an unusual heart rate value is detected. In the smart home industry, applications that act like home intelligent assistants, controlling home sensors or actuators are becoming very popular. The Wink [17] and the Samsung SmartThings [18] are currently the most popular hubs on the market. Both have their applications in leading application stores. These hubs allow the integration of smart systems and other devices and the manipulation of them all through a mobile device. Washing machines, refrigerators, vacuum cleaners, lamps, irrigation sprinklers, air conditioning are some examples of smart devices that can be easily controlled. These hubs have an architecture that can integrate new devices, however, this process is not always flexible. In smart home environments or IoT networks, data-related issues, such as storage, retrieval, processing, and security, are major concerns. These systems usually adopt cloud computing architectures that must be designed and developed taking into consideration these issues and the integration of third-party applications [19].

2.1 Contributions

The presented work gathers contributions from the above study. When compared with other solutions presented in the literature, the system proposed in this paper differs from them because it offers a service-based architecture, called HIAS, prepared for the integration of third-party applications with a security model for user and data privacy. Moreover, this ecosystem for smart homes considers not only indoor solutions but also outdoor applications that interact with the HIAS. Moreover, the HIAS ecosystem creates ubiquitous communication scenarios where persons can be constantly monitored. The next sections will present the HIAS architecture and integrated solutions in detail.

3 HIAS Cloud Architecture and Security Implementation Details

This section presents the design and implementation details related to the cloud architecture of the IoT-based healthcare ecosystem and the security mechanisms implemented. This service-oriented architecture, called HIAS, was design with three main requisites: (1) Easy integration of new users, applications or other devices, such as, sensors and actuators; (2) the ecosystem should consider indoor and outdoor scenarios, including mobility environments; and (3) All health data and user authentication should be private and secure.

3.1 HIAS Service Based Architecture

The HIAS system architecture is an model-view-controller (MVC) architecture, and so there are three main pillars, which are:

- Model: The main component of the architecture execution. This is responsible for modeling, storage, retrieval and process data.
- View: The purpose of the view is to present to clients all the information presented in the system. It is the user interface layer.
- Controller: This layer receives information and data that interprets, changes if necessary, and sends to the model.

All clients (users, devices, etc.) communicate with the HIAS through HTTP requests and HTTP responses, and all information is exchanged between the server and clients in JSON format, a simple and fast format. This system is also present in the models. Data models are responsible for aggregating and matching all acquired data. The view is responsible for sending and receiving the data. The view does not care about the data types or how they are acquired, it is only limited to visually presenting the result. In this case, it is responsible to send information for applications that complete this system. All services that are part of the controller add, update, extract or read data from the database. These services were developed in an ASP .NET Core Web Application in C#, which offers object-oriented programming and freedom to interact with other software developed in other programming languages. Figure 2 describes the HIAS service-based oriented architecture. Each service has an associated HTTP request link. Then each customer selects the services they want to use and links them to the source code of the software they are developing. Since HIAS is a service-based architecture, services are the main pillars of the whole system. As mentioned earlier, and to integrate various applications and software into one architecture, the services were developed aiming at to allow CRUD operations on data. To read the information present in the database is used the GET method. This method was chosen because it does not allow the modification of the data.

To add and update the data, the POST method is used. Requests using this method are never cached and do not remain in the browser history, which ensures high security for this system. These POST requests have no data length restrictions, which allows large data to be used by this method. One such example is the electrocardiographic readings, which is a fairly long list of data but is saved from the database without any problem.

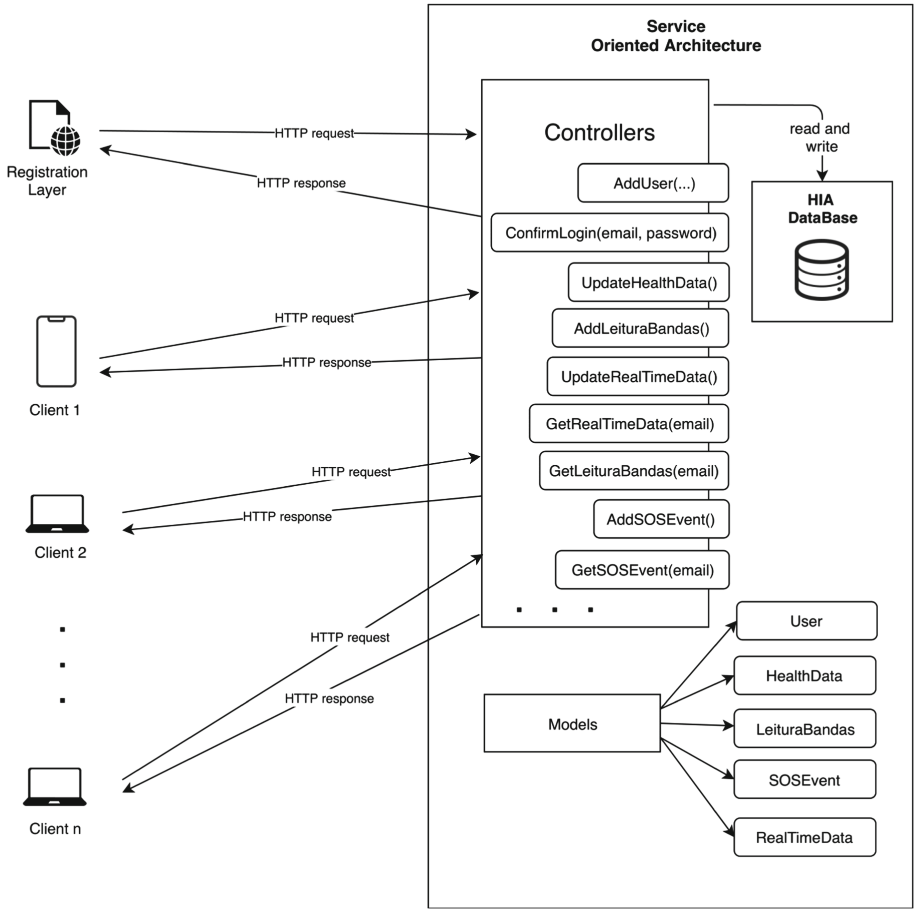

Fig. 2. IoT ecosystem service-based architecture.

All of these services make a direct connection to the database and, depending on what they do, execute SQL commands to manipulate or query information. Finally, add and update services return a flag depending on the execution of the command - success or failure flag. There is also in this system a single registration layer for all applications: the user will only need to register once and will be able to login to all applications that are part of this universe. This is because there is a unique database shareable between all applications.

3.2 HIAS Security Mechanisms

The constructed and implemented security procedures' main goal are to increase communication security between systems while decreasing their development time. These processes can be handled by dedicated modules. These modules are bundled with the systems and are responsible for producing secure and privacy-oriented communication channels between the constituents of the ecosystem. As such, constituents of this system do not communicate directly with each other, depending on the security modules to produce communications.

The security modules are composed of a public-key pair, a certificate signed by a trusted authority and three different services responsible for (1) receiving information from the associated device. This process consists of a service running locally on the associated device that receives information the device wishes to send over the network; (2) sending information to another security module. A service is responsible for producing an SSL socket connection with another security module using the certificates for authentication. Afterward, an ephemeral public-key pair is produced and an ephemeral public key (its pair) is sent to the receiving security module. With this, a key exchange protocol produces a different session key for each transmission sent over the connection. Each transmission sent is encrypted with a unique session key using public-key cryptography.; and (3) receiving information from the security module of another device. A service that handles receiving information sent by another security module. The data that is received is decrypted using public-key cryptography and validated for transmission errors. If valid, the now decrypted information is communicated to the device, for it to perform whatever function is required. The security modules function somewhat as a black-box, where information is sent and received without it affecting the structure and inner workings of the associated devices. Has may be seen in Fig. 3, these modules are fairly independent of the devices that are associated with them.

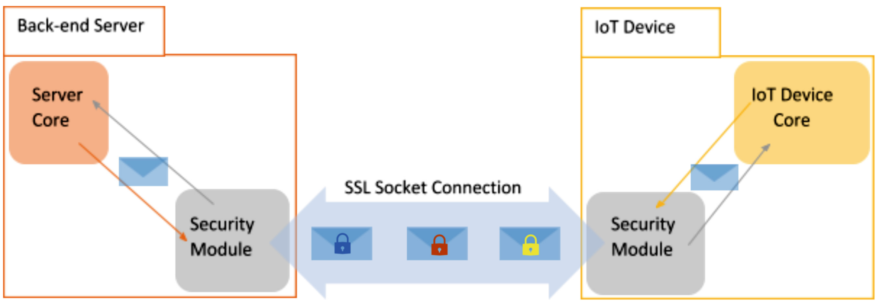

Fig. 3. Representation of the ecosystem security procedures and its modularity.

Development, maintenance, and updates of these modules can be performed in separate of the IoT solutions. By having several abstractions on the architecture of the system to allow for these modules to work associated with the IoT devices, only minor changes to the security modules are be needed for them to function in different IoT devices and systems. As a result, development times of security solutions can be cut down because of the increased interoperability of different devices or systems with the security modules. This increasing focus on the development of a smaller number of security solutions instead of a dedicated security solution for each device or system, possibly resulting in an overall boost in solution quality.

4 IoT Solution for Outdoor Emergency Scenarios

This section presents an IoT solution integrated into the HIAS, for outdoor scenarios, specifically for emergencies. This solution's main goal is to react and facilitate the communication between users and the emergency services, through the HIAS system. This solution is able to monitor his user's health status and location and send this information in real-time to the HIAS. In case of an emergency, and if the user is unable to contact by himself the emergency services, the home intelligent system will contact them automatically (or a familiar). This IoT solution also includes a voice recognition application that enables a faster reaction and action from the caretaker. This application can be used by a familiar, through the HIAS, or a third-party client, such as an emergency service operator. Therefore, as may be seen in Fig. 4, this outdoor IoT solution includes three different applications, a smartwatch application, a mobile application, and an operator application. A security module, named MD BARS, was also implemented and it's integrated with the HIAS security procedures.

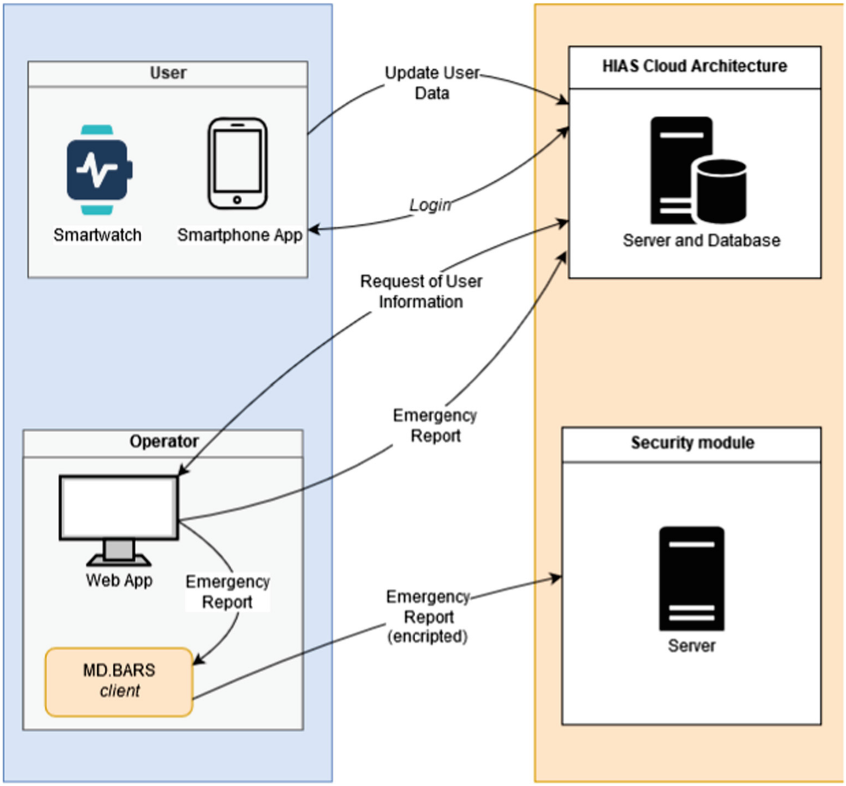

Fig. 4. System architecture design of the outdoor IoT solution for emergency scenarios

The smartwatch application has the objective of providing the system with real-time data about his user's heart rate and body temperature, by using the sensors integrated into the device. At the same time, the app should be able to detect any dangerous values and automatically trigger an emergency request. The collected data is then transferred to the smartphone application (Fig. 4) where his user can it will be processed and presented to the user in graphical form. Besides that, the mobile app also allows the user to login to his HIA account and edit his personal and health information (Fig. 5b). Information such as the user's age, health condition, and medical history can also be valuable to the emergency agents, however, it is a hugely time-consuming task to describe them with accuracy in a stressful scenario. The final piece of information collected by the mobile application is the device location. The app takes advantage of the powerful GPS, that the majority of modern smartphones possesses, to provide accurate data about his user's location and, in case of an emergency, collects real-time updates about it. To start an emergency call, all the user has to do is access the application and press the button on the center of the screen (Fig. 5a). This will trigger two actions: first, a request will be sent to the central server, informing that an emergency call has been initiated, and at the same time, a call to the predefined emergency number will be triggered.

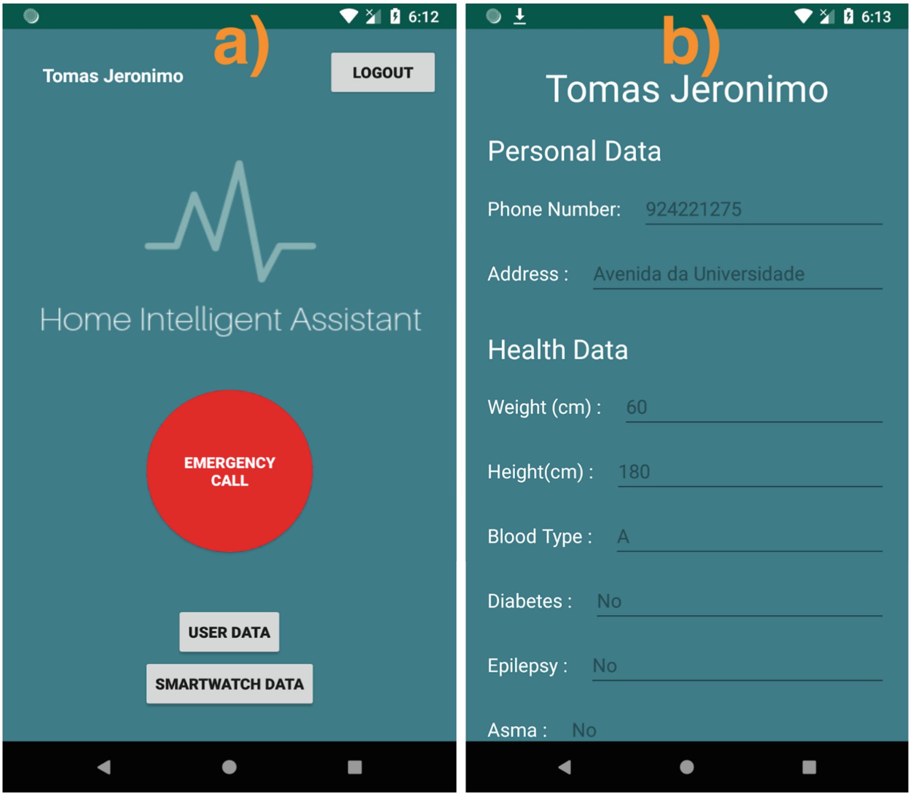

Fig. 5. Smartphone application interface. (a) The main activity interface; and (b) The user health information interface.

The final application of the outdoor IoT solution that is integrated with the HIAS is a web application, and it can be seen in Fig. 6. This application can be used by emergency operators, or informal caretakers (friends or familiars) through the HIAS. The main goal of this application is to provide them with the most relevant information about each situation, reducing to reduce the time required to evaluate each emergency call and deploy the appropriate rescue agents. In order to achieve this, at the beginning of the call, the application will immediately present the user's heart rate, body temperature, and location. This will give the operator some basic information about the user's situation and health status before the conversation between them even starts. Then, during the call, the operator's voice will be processed using a speech recognition algorithm to detect whenever he requests new information. These requests are then processed by the application that tries to respond with the data at his disposal. After the end of the call, the operator is required to give a summary of the situation, and this will be sent to the central server, and added to the user's history.

Fig. 6. Emergency web application of the outdoor IoT solution. Interface displayed in the HIAS application.

The communication between these three applications is only possible because of the HIA service where they are integrated, where a central server and database allows the exchange of information among them. The communication protocols between each application and the central server were developed to allow secure data exchange and maintain user's privacy.

5 IoT Solution for Indoor Monitoring Scenarios

This section presents an IoT solution integrated into the HIAS, for indoor scenarios. This solution allows us to monitor in real-time the user's heartbeat and respiration while sleeping, resting, sitting on a chair or couch through the support of biometric sensors, specifically through a chest band (Fig. 7a). This chest band is a research product developed by PLUX [20]. A mobile application (Fig. 7b) was constructed and used as a gateway for relay data from the sensors to the HIAS, through the Internet.

However, communication between the sensors and the smartphone is made via Bluetooth. While wearing the chest band, the user or a familiar start the mobile application that will collect, process and send the data to the HIAS, for storage and analysis. This solution was constructed and aims the detection and prevention of the activation of the autonomic nervous system while sleeping. However, it can be used in other indoor scenarios. The only requirement is that users should not be in movement around the house. One possible scenario is the real-time monitoring of habitants' heartbeat and respiration while watching TV or reading a book.

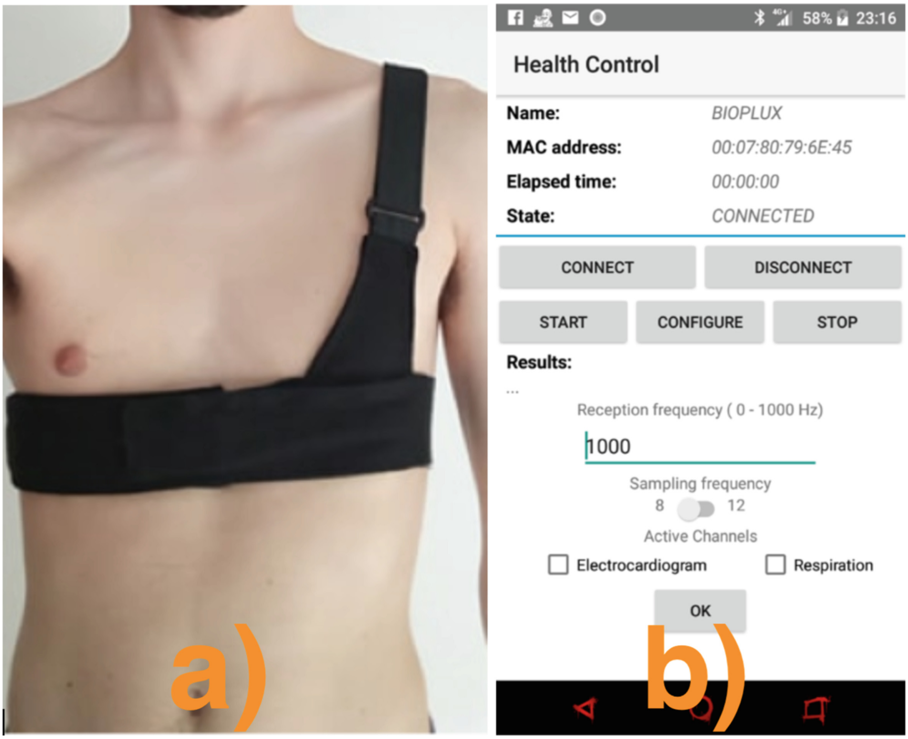

Fig. 7. (a) Chest Band used for health data collection; and (b) mobile application to collect and forward user data from sensor to the HIAS

Considering the above scenarios, when the application starts will be required authentication data, so, if the user is not registered in the HIAS system, he can perform the registration, and after, perform the login, so that a unique user can access all functionalities and store his biometric data, or visualize his past acquisitions. The mobile device must support the use of Bluetooth since the chest band connects to the mobile via Bluetooth, and, in case it doesn't have, the user will only be presented with limited functionalities, such as a list of previous acquisitions and analysis of preliminary ECG and Respiration graphs. The communication between the device and the chest band can occur in the classic Bluetooth connection or using Bluetooth Low Energy. As there is a possibility that there are several chest bands in the area, it must be selected of the list the desired one comparing the presented MAC address on the screen with the one registered on the band. This application allows the user to select the acquisition parameters such as Reception Frequency and Sampling Frequency, defining the accuracy of the receive data and presentation of the graphs. It already has standard values if the user doesn't want to change them. On acquisition mode, the data sent by the Bluetooth device are received asynchronously by the mobile device and then sent to the local broadcast receiver, using a specific object.

After all the health data is collected, it is sent to the HIAS integrated database through HTTP requests being stored for posterior visualization. This data consists of three columns, being the first the total milliseconds of acquisition, the second and the third is the value of ECG and respiration at a given time respectively. The ECG works detecting and assigning values to the electrical signals generated by the heart. Respiration is obtained indirectly, by measuring body volume changes such a thoracic circumference. For this to work is was used as an API developed by Plux company that can be found at their website [20], which consists of a jar file containing all the API object code. As mentioned earlier, this application allows data visualization from a past biometric acquisition. For this purpose, the application performs a request to the database allowing the user to select the desired one from a list sorted by date. After the selection, another request to the database is made so, it can return the data to populate the graphs and calculate the values of heart and respiration rate values (Fig. 8). Based on sex, age, and weight, if a certain biometric acquisition has abnormal ECG or respiration value, a notification is triggered informing the user and advising him to visit a health professional.

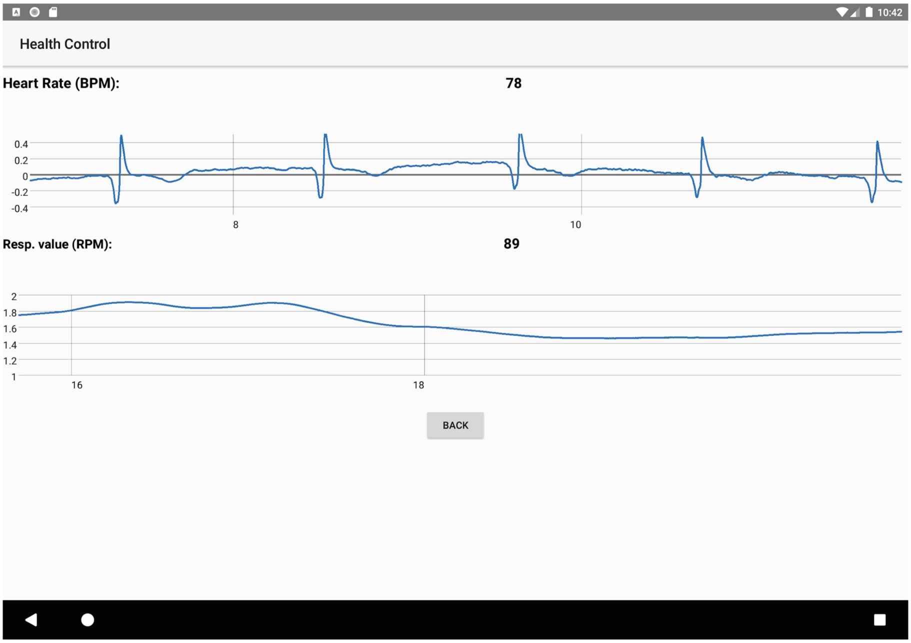

Fig. 8. Heart rate and respiration values displayed in the HIAS application.

6 Conclusions and Future Work

This paper presented an IoT-based healthcare ecosystem for Home Intelligent Assistant Services in Smart Homes. This work main goal consists of real-time monitoring and reaction to hazards situations through the integration of IoT solutions for indoor and outdoor scenarios on a Home Intelligent Assistant, called HIAS. It considers three main components: a modular service-oriented architecture, an indoor system for biofeedback monitoring while sleeping or resting and an outdoor emergency call/react system. Moreover, a module for secure authentication and privacy was constructed and implemented. The presented ecosystem includes the use of mobile devices and wearable sensors. It is very easy to use in terms of design and usability. Although is not focused on elderly people, it requires a small interaction among users and devices. This ecosystem architecture was constructed and implemented, considering the interoperability challenges that these networks usually have. Therefore, the system is prepared to integrate other third-party solutions.

As future works, experiments with real users to evaluate the correct operation of this ecosystem will be performed, considering the users' satisfaction and usability. Furthermore, it will consider the integration of more applications within this framework. The main future goals for this ecosystem are advanced interoperability and security research.

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