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Secure low-cost solution for elder's eCardio surveillance

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Abstract

In recent years we have assisted to the growth in two major areas related to eHealth: one dedicated to the conception, creation and implementation of biosensors and another dedicated to the monitoring of vital parameters provided by these sensors. Furthermore, the exponential growth of mobile technologies and the widespread use of mobile devices embedding standards of next-generation *Personal Area Networks* (PAN), such as the *Bluetooth Low Energy*, come to revolutionize the way the monitoring of vital parameters is done, now following the anytime and anywhere approach with further energy efficiency. The work presented in this paper brings together the technologies addressed above in order to create a ready-to-use, simple, efficient, safe, low-cost and compatible solution capable of monitoring vital parameters and generate alerts in the presence of abnormal values. The tests showed the simplicity of the system setup, which is an important feature for elderly, demonstrated the reliability of measuring values and alarm rising, and also the warranty of data confidentiality.

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1. Introduction

With the growing number of biosensors to be designed and built today and with the constant advances in technology, it becomes imminent the creation of wearable sensors that will function as the monitoring of vital parameters. These biosensors will facilitate much the monitoring of elderly people that lives alone in their homes or who have nobody to turn to in case of need. If we add to this fact the constant adoption of smartphones by the people and the increasingly integration of mobile communication technology of last generation for *Personal Area Networks* (PAN) on them, then it will be possible to carry out effective monitoring, in real time, and will therefore be possible to generate alerts in the event of a change in vital parameters of a person that endangers its life. It is also possible the monitoring anytime and anywhere because smartphones increasingly have capabilities to connect to the internet via wireless networks (*Wi-Fi* and *3G/4G*). With the recent appearance of the technology *Bluetooth Low Energy* is now also possible to use sensors with low power consumption that allows a sensor to require practically no maintenance.

With the increasing life expectancy of the developed world population and with the constantly aging of them, this becomes an increasingly important thematic because it is necessary to create solutions that optimize the traditional health systems, enabling more availability without implying a bigger effort of the health professionals. Therefore, the remote monitoring systems of vital parameters arise to fill this need.

To meet this need, in this paper, we will describe a system that will make the monitoring of heart rate and will going to transmit to a monitoring center which will generate an alert if the value of the parameters is considered dangerous to the health of an elderly. Will be developed a simple prototype, ready-to-use and, at the same time, reliable, safe and cost effective and compatible with next-generation smartphones.

In the next chapter we will present the architecture of the solution and how it works, specifying the elements of the solution and how the communications between them are performed. In chapter 4 we will discuss how we implemented the various components of the solution, as well as the results of the tests conducted on some elderly volunteers. In the last chapter we will make some final thoughts and we will talk about some work that we intend to do in a near future.

2. Related work

Over the last years eHealth care research area has been taking different paths such as i) sensors and actuators construction, ii) antennae and radio communication suitability (human body is 80% water), iii) signals capturing to infer disease or health problems patterns (health monitoring), among others, in order to monitor the risk of vulnerable people. With the appearance and dissemination of resource rich smart phones and PDAs with personal computer similar capabilities, the eHealth monitoring can now be done in a real-time, anytime, anywhere approach. However, the connection between mobile phone and the human body monitoring system (usually a *Wireless Body Area Network* – WBAN – composed of some sensor nodes) is still an open problem in many presented solutions for two different reasons: i) the solution relies on external smartphone adapters or external gateways (e.g. *Zigbee*) or ii) there is a direct connection but it has low data rate (e.g. *IR*) or it is not energy efficient and takes too much time for connection establishment (e.g. *Bluetooth*). ECardio system presented in this article solves this problem by using direct connections following an energy and timely efficient approach.

Focusing now on the sensor nodes, a WBAN could be characterized as implantable or wearable. In implantable WBANs sensor nodes are under the skin of the patient, while in wearable BANs sensor nodes are embedded in cloths or near the skin surface. Wearable WBANs can also be split into wired and wireless, according to the type of used medium to connect sensor nodes. For specific WBAN information on implantable and wearable technologies see [1] and [2]. Due to the type of solution presented in this article, this section focuses on wearable health monitoring solutions.

Generally, wearable health monitoring solutions can be applied into three big domains: a) in hospital and disaster events, where the aim is to facilitate or accelerate the response to be given to patients by, for example, enhancing the triage process or collect data at disaster site and notify target hospital about the patient conditions even before patient arrival, b) motion and activities of daily living where the aim is to detect abnormal movements

(e.g. hip recovering) or to reconstruct person activities and locations, and c) residential healthcare monitoring. ECardio solution fits in this last domain.

Residential healthcare monitoring are very important and strategic applications because in most cases they release places on hospitals once patients can be at their homes while being monitored by the physician personnel. For example, in [3] it is presented a wearable health monitoring system targeted for children. The system senses temperature and heart rate and a smartphone processes acquired data in order to fire alarms to the parents. While this solution uses *Bluetooth* and is targeted for non-critical situations, eCardio uses *Bluetooth Low Energy* – BLE - and is targeted also for critical situations. In [4] it is presented a system very similar to eCardio. It can make use of a large range of OEM sensors (personalization) and a smartphone for local processing to save communication costs. ECardio follows other approach in this matter as it sends data to the control center in order to guarantee maximum feasibility in diagnosis and alarm rising. Another difference is that eCardio promotes longer system operation by adopting BLE as the communication standard while this project has adopted *Bluetooth*.

iCare systems [5] and [6] both use body sensors and smartphone in order to establish a mobile infrastructure to monitor elderly persons. Like eCardio, these projects offer remote monitoring and alarm conditions anytime, anywhere but they employ *Bluetooth* as the wireless communication standard for connection between smartphone and body sensors which differentiate them from eCardio in terms of energy savings.

Edward, Amy and Matthew [7] present a project to integrate various vital sign sensors by using MICA mote platform and *RFID* for localization. However, unlike eCardio and previous described solutions, this project is tailored for indoor only environments, like homes and hospitals. In the same perspective, Ching-show et al. [8] present a home care system for elderly which collect data through *ZigBee* network and issues alarms when abnormal data is read. Like [7] this healthcare system is tailored for indoor healthcare environments.

In order to save personal resources, the authors of [9] present a solution for mobile healthcare system which incorporates a mining module. The solution is called “Intelligent Mobile Health Monitoring System (IMHMS)” and it is the mining module which infers abnormal data readings. Although the mining module seems to be an interesting approach, authors defined *Bluetooth* and *Zigbee* as communication standards for connecting WBAN network to the mobile phone or home PC, which requires an external adapter when *ZigBee* is used or consumes too much energy when using *Bluetooth*. Another solution which uses mining techniques in the control server is presented in [10]. This solution is called UMHMSE and monitors elderly health, mobility and location. The health monitoring is supported by a *Bluetooth* based body sensor network and the mobility is acquired using mobile phone accelerometers while location is inferred using GSM infrastructure.

Taking the recent cases of failures of life saving medical devices such as drug delivery systems, as reported by Food and Drug Administration (FDA), the authors of [11] focused their research work not on building a reliable mobile healthcare system but in a framework to automatically generate code for both body sensor network and for smart phone based on high level specification of requirements. However, the framework supports only *Bluetooth* and *ZigBee* communication standards and, as already referred, these are not the most suitable communication standards for mobile healthcare systems due to energy consumption and external modules need. SPARTAN [12] is another framework projected to facilitate the process of developing body sensor networks’ systems.

It is clear that eCardio system distinguishes from all other mobile health monitoring projects in the communication standard used to connect body sensor network and the portable device. We believe that *Bluetooth Low Energy* is the most interesting communication standard due to two main characteristics: i) support in the recent smartphones (direct and seamless connection) and ii) the low power consumption.

3. Architecture

The solution architecture makes explicit the elements of the system as well as how it interact with each other. A good architecture specification determines a successful result when we pass to practice. So, in this section we are going to present the architecture of the solution. We will also explain the mode of operation and the interactions between the different modules of the solution, explaining how the information gathered by the different sensors is handled.

3.1. Architecture

The figure below represents the overall network architecture of the solution where are shown all the communications that are carried out in the system.

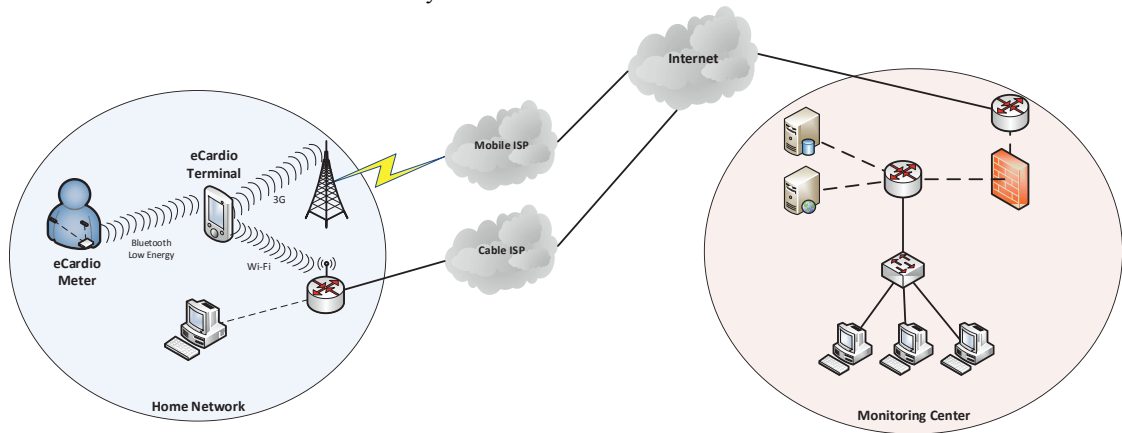


Fig. 1. Overall network architecture of the solution

Notice that in the figure we can split the architecture into two distinct blocks: the Monitoring Center and Home Network.

The Monitoring Center is where the data collected from elderly are classified, processed and stored. It is here that preventive actions are triggered in the event of an abnormality in received heart rate values. These actions pass for warning the caregivers of the elderly in question and warn the emergency medical teams indicating them the location and data of the elder so that they act in conformity as quickly as possible.

The Home Network is the place regularly frequented by the elder, typically this is its home. Here, the architecture is composed by two elements, the eCardio Meter and the eCardio Terminal. The eCardio Meter is composed by all the sensors that perform the measurement of the heart rate. This one, when making a heart rate reading of the elder, will send the value to eCardio Terminal. The eCardio Terminal is the terminal in charge of making the communication between eCardio Meter and the Monitoring Center. This one simply receives the data from the elder heart rate and then sends them through the internet for the Monitoring Center where they are going to be analyzed and stored. At Home Network can still be present a computer with internet access where the elder can consult their health history.

3.2. Operation

The functioning of the solution is based on the gathering of heart rate of the elder and sending it to a Monitoring Center. In order to make clear how it handles this procedure we then explain it.

In the beginning, the elder must have putted in their bodies the sensors that compose the eCardio Meter. These sensors will be responsible for performing the reading of the heart rate value. In the figure 2 you can see a generic schema of the elder with the sensors placed on.

In the schema of the figure below you can see the example of an elder with the eCardio Meter which in this case consists of a strap onto the chest that transmits through *Bluetooth Low Energy* (BLE) the measurements of heart rate for eCardio Terminal.

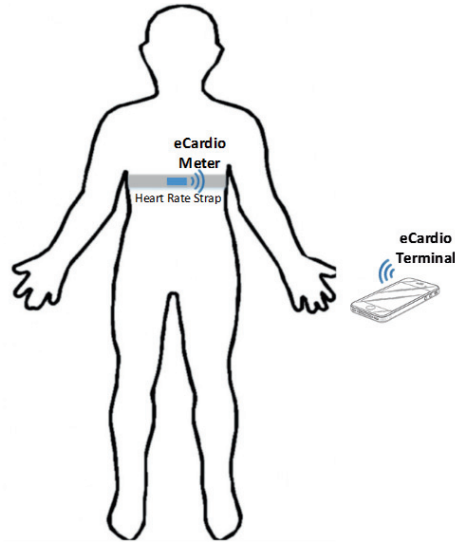


Fig. 2. eCardio Meter usage schema

In the following figure we can notice all the interactions that take place during the system's operation. These interactions will be explained below in greater detail.

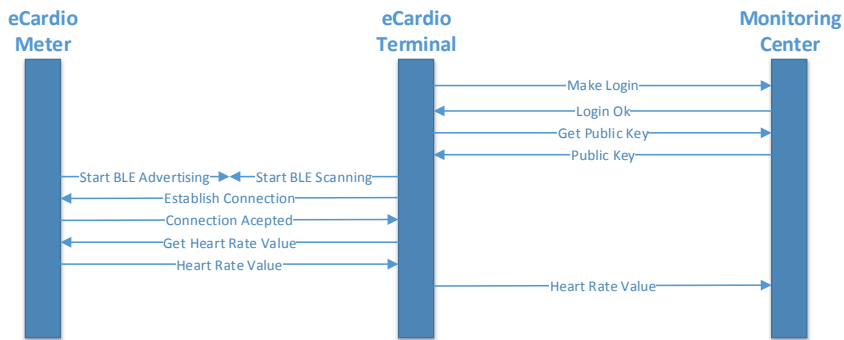


Fig. 3. Solution's communication schema

In the eCardio Terminal, when is launched the application, the elder must insert their username and password in order to authenticate to the Monitoring Center. After the successful login, the application will require to an existing server in Monitoring Center a *public key* to *encrypt* the heart rate data to be transmitted. After all the conditions required to start reading and transmitting the data are fulfilled, the eCardio Terminal changes the state of the BLE to *scanning* in order to be able to discover the eCardio Meter.

The eCardio Meter is constantly connected, but it can only be found by the eCardio Terminal if it is placed on the elder. When it is properly placed it is in *standby mode*, in other words, the eCardio Meter is connected but it is in a mode of very low power consumption which increase the longevity of the battery. When eCardio Meter detects the presence of an eCardio Terminal in its proximity it changes the state of the BLE to

advertising mode so that the eCardio Terminal can be able to find it. The eCardio Meter, which has the BLE active on the *discovery mode*, when detects the eCardio Meter will establish a connection getting defined as *master* and the eCardio Meter as *slave*. After the connection establishment both devices will be staying in *standby mode*, just changing its mode to *connected* when the eCardio Terminal request the reading of the elder's heart rate value.

The eCardio Terminal, when retrieving the value of heart rate from eCardio Meter, will *encrypt* it using the *public key* previously requested and will send the result to the Monitoring Center through the internet using a *Wi-Fi* connection which it is connected or a connection through *3G* or *4G* mobile networks.

At the Monitoring Center, the data that are received are *decrypted* with the *private key* and processed. In a first stage they are compared to the standard values of the heart rate of the elder which they belong and then they are stored for statistical purposes. In the event of the values received are abnormal, an alert is generated with the data from the elder to his the caregiver and to the emergency medical teams so there is a fast acting accordingly to the situation.

4. Implementation and tests

The implementation of the solution architecture is essential to demonstrate a good architecture specification. Become even more essential in this scenario the tests to this implementation that will verify and validate its proper working. So, the architecture was implemented and tested in the elderly in order to verify its proper operation. In this section we begin by presenting the implementation details of the solution and then the tests performed on it as well as the achieved results.

4.1. Implementation

In order to implement the system we choose to use *Bluetooth Low Energy* (BLE) for the communications between the eCardio Meter and the eCardio Terminal. This required a smartphone with BLE capabilities and a sensor for heart rate monitoring also with such capabilities.

We chose to implement the system using the BLE technology because it is a technology for short range and has a very low power consumption. The last factor was decisive in the choice of this technology since we need to have a high autonomy in the eCardio Meter in order that the need for exchange of the battery is made in a temporal cadence the largest as possible. The BLE has its genesis in techniques that allow that the most of the time the devices are in execution, they are in *standby mode*, reaching consumptions of $1\mu\text{A}$ and consuming an average of 12mA when they change their operation mode to connect. This contributes for the size reduction of transmitted packets in communication, compared to the traditional *Bluetooth*, and the process speed the state transition. The mode transition was another of the great new features introduced in BLE, compared with traditional *Bluetooth*. The BLE takes about 3ms on the transition from *standby* to *connected mode* and vice versa, which makes it faster and so it stay less time in the *connected mode*, saving energy. This time saving also allows the BLE takes much less time on the pairing of devices, solving one of the major drawbacks of the traditional *Bluetooth*.

We chose to use an iPhone 5 smartphone with the iOS6 operating system because it is the smartphone where the BLE technology is more mature and where the integration of the capabilities of the technology are more developed. In this smartphone we developed the eCardio Terminal, a mobile application that will make the management and the control of the eCardio Meter. To accomplish this we used the *framework CoreBluetooth* available on the API from iOS6 to perform the connections through BLE technology with the eCardio Meter. In order to manage the access authority to the heart rate values measured by the eCardio Meter it was still implemented a *profile Heart Rate* which is specified by the Bluetooth SIG, and determines the parameters which are accessible of a device which implements it.

For the heart rate monitoring sensor we used the Wahoo Blue HR Heart Rate Strap that sends the heart rate data through BLE technology. This sensor is composed of an elastic band which contains electrodes that are directly connected to the central node where is made the measurement of heart rate and where are managed the data communications. This type of sensor is the ideal for make the measurement of the heart rate, because of the use of

electrodes which minimizes the measuring errors and this factor is fundamental to the system because these are vital parameters. To validate the reading of the heart rate values we used a doppler which is often used to measure the heart rate of a fetus during the pregnancy.

At the **Monitoring Center** we implemented a firewall to protect the elderly's data, since it deals with highly sensitive data. This firewall has been implemented using the ClearOS Linux distribution and has its default behaviour of blocking all connections and only open the ports that we were going to use. So has been opened the port 80 to allow access to the web interface where the elder can consult his health history, and the port 8080 which is where the *Webservice* is listening.

This *Webservice*, that we also implemented, is a *SOAP Webservice* developed using the *WCF framework* and it will be the connection between the eCardio Terminals and the database and it will be responsible too for the authentication of the eCardio Terminals with the service and provide them the *public keys* to *encrypt* the data.

Was even developed a *webpage* where elderly have the possibility to register yourself and consult the information from your health history. This health history is generated based on the values of heart rate collected by the elderly's eCardio Terminals.

4.2. Tests

In order to verify and validate the proper functioning of the system were conducted some acceptance tests. These tests were performed with 5 volunteers aged over sixty years, with the average age of seventy-four and a standard deviation of eleven. The subjects were in good health and were technologically illiterate. Of these, three were males and two were females.

Each elder was subjected to the monitoring of his heart rate during a period of 10 hours for the system could gather these values. To accomplish this, the eCardio Terminal was calibrated to gather the heart rate value three times every hour for testing purposes. During that period, the elderly were to carry out the activities of their daily living. In the figure below is shown an elder with the eCardio Meter placed and an eCardio Terminal gathering the heart rate value and sending it to the Monitoring Center, from where the elder consulted through internet their health history.



Fig. 4. Scenario of the measurement of the heart rate values

Below will be shown the tables with the results gathered in the measurements as well as the acceptable maximum and minimum values to each one of the elderly.

Table 1. Results of the measurement of the heart rate values

Subject	Measurement Number																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
A	52	56	54	55	49	53	57	60	62	59	60	58	55	52	55	56	50	53	54	56	53	55	51	57	55	51	53	54	52	56
B	73	69	65	68	74	76	73	78	77	84	82	79	76	78	77	78	76	73	75	72	70	71	69	67	70	74	76	73	72	69
C	62	67	65	68	70	72	69	64	67	66	63	61	59	62	65	63	64	66	64	68	71	67	64	65	68	67	63	66	68	65
D	59	58	60	65	63	60	64	68	69	67	64	63	65	62	59	63	65	62	63	61	64	66	65	63	63	61	64	63	65	62
E	77	73	75	72	69	72	73	75	78	80	76	73	69	71	73	74	75	72	74	72	68	70	73	76	75	74	72	71	75	74

According to the age, the biophysical parameters, the pathologies and the medicines taken for each subject you can see in the table below the maximum and minimum values acceptable for the heart rate. In the event of the gathering the heart rate of the subjects if one exceeds the maximum or fall below the minimum, for his age, an alert is generated for his caregiver and to the emergency medical teams.

Table 2. Maximum and minimum values acceptable for heart rate of each subject

Subject	Age	Max	Min
A	60	80	45
B	87	90	50
C	67	90	50
D	84	90	50
E	62	90	50

For an appropriate assumption of these maximum and minimum values the biophysical parameters, the pathologies and the medications of each subject must be provided by a doctor, because according to the situation of each one is possible that the maximum and minimum values are different, for instance from the variation of the heart rate gathered for the subject D we can conclude that he was under the effect of *beta blockers*.

The subject A, a male with the sixty years old, does physical exercise every day. For that, he does about one hour of jogging every morning. So according with the gathered data, we observe that these are comparatively low because the average lies substantially in the 55 bpm. This is due to regular physical exercise, which means that the heart is exercised and in each heartbeat it sends much more blood than the usual. In the figure below there is a chart that shows the variation of the heart rate for the subject A.

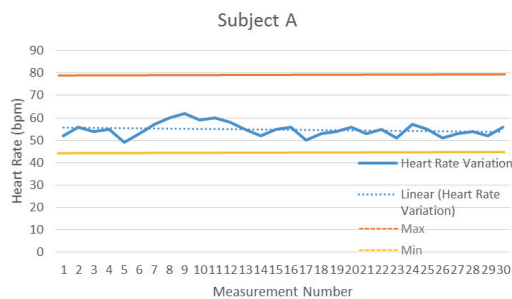


Fig. 5 Chart of the results of the measurement of the heart rate values of the subject A

The subject B, male with eighty-seven years old, is an elder with relatively advanced age and carries a normal lifestyle, trying not to commit excesses in order to preserve his health. According to the heart rate data gathered we observed that the values are within the normal range and the average is 74 bpm as shown in the chart of the figure below.

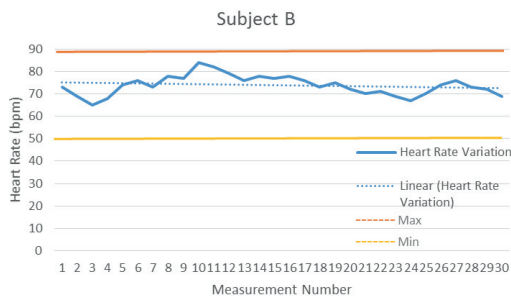


Fig. 6. Chart of the results of the measurement of the heart rate values of the subject B

The subject C, female with the age of sixty-seven, leads an active lifestyle, trying to be healthy in her feeding and to reduce the stress of everyday life she practices yoga once a week. We can see in the chart of the figure below that the variation of her heart rate is lower compared with the other subjects as a result of her weekly yoga, taking an average of 66 bpm.

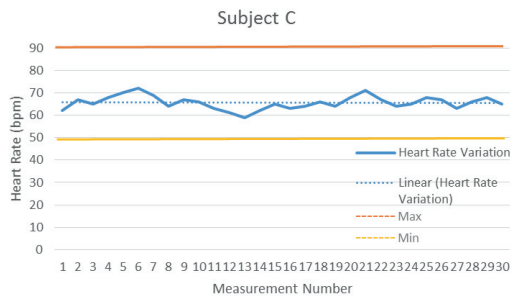


Fig. 7. Chart of the results of the measurement of the heart rate values of the subject C

The subject D, a male with eighty-four years old, has some health issues not too much severe, and he has to take some medicines daily. On the chart of the figure below, we can see that there are wide variations in his heart rate, recording an average of 63 bpm.

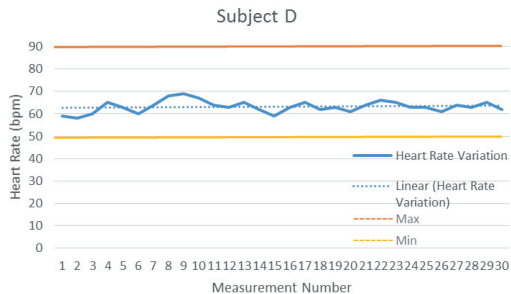


Fig. 8. Chart of the results of the measurement of the heart rate values of the subject D

The subject E, a female with the age of seventy-two years old, takes a lifestyle considered normal, but it is an extremely nervous person. This nervousness can be seen in the chart of the figure below where we can see that the variations in the heart rate are somewhat irregular and a little high. Her average stood at 73 bpm.

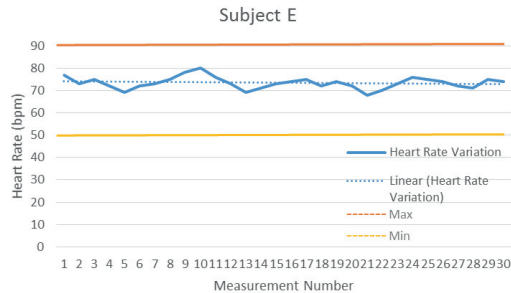


Fig. 9. Chart of the results of the measurement of the heart rate values of the subject E

5. Conclusion

This project presents a solution capable of monitor vital parameters and generating alerts to the caregivers and to the medical emergency teams in the presence of abnormal values.

A prototype was created in order to test the solution in a real environment. Of this test it was verified that there was a wide acceptance of the concept by the elderly, since the prototype was practical and discreet allowing them to live a normal life, leading to that some have even forgot that were using it. It was also verified that the gathered data that has been performed with the prototype was accurately, by comparing simultaneously the results measured with those measured by a doppler.

According to the results achieved we intend, in the near future, extend the target population and apply this solution to other population groups that need a constant monitoring of their vital parameters such as Alzheimer or diabetic patients. We also intend to be able to calculate the maximum and minimum heart rate value for each subject depending on his activity is in effort or not and through other factors.

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