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Healthcare monitoring system for web-enabled smart buildings

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***Abstract*— This paper describes the implementation of a wireless healthcare device in a web technology based smart building. The device has multiple communication interfaces like Bluetooth and 6LoWPAN, and multiple monitoring processes. The system will allow remote monitoring of various vital signals in hospitals, homes and various other places in real-time providing support for people having chronic illness, any other medical risk or home rehabilitation. The system has a quite low power consumption even if it has capabilities to monitor multiple parameters like body temperature, respiration rate, ECG, blood oxygen saturation level (SpO2), pulse rate, blood pressure and body position having the capability to alert in case of fall detection. The primary objective is to show how would be possible to seamlessly implement a healthcare system into a smart building based on Internet of Things concept and using web technologies through the HTTP open protocol for easier integration and configuration through features meshup process.**

***Index Terms*—healthcare, REST, Web of Things, smart buildings.**

I. Introduction

The population of the globe is increasing rapidly but in the same time aging people's number is increasing as well, and will reach almost 2 billion by 2050, that's around 22 percent of total population according to [1]. Health issues related to elderly people are very complex starting from injuries by falling to cardiovascular diseases, diabetes, hearing and seeing problems to more severe brain illnesses, therefore, is a big need for solutions that could prevent this or help in recovery from an acute event.

Many years ago, Weiser [2] had a vision and defined a direction for pervasive computing research, he stated that "*The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.*". He was the first to point over the idea of miniaturization and ubiquity of sensors and that visible hardware and protocols will move into an invisible background, in other words, that technology becomes so seamlessly integrated that it's used naturally without noticing it. After massive research made in the field of sensors, and wireless communications led to the development of various small, low power and intelligent wearable wireless sensor devices. Wearable sensors in Wireless Body Area Networks (WBANs) provide individual real-time, physical monitoring and data collection of basic health parameters in different places without needing any other devices for that purpose. There are numerous parameters that can be measured starting with simple ones like body temperature, respiration rate or pulse rate, continuing with more complex ones like motion detection and blood-glucose level measurement and even more complex ones like ECG, EEG, blood pressure, epileptic seizures and so on. Besides various sensors there can be some actuators, for example, to apply the correct dose of injection when that's needed based on measured parameters.

There are more and more wearable monitoring devices starting with the most simple ones that measure some basic parameters like pulse monitor to others that has multiple features, wireless communication, small size and small power consumption, but the majority can't be simply included within a system to collect data and interact with them.

Nowadays, smart phones together with other network-enabled devices get widespread. Therefore, they could be integrated into our lives in order to make everything around us much easier to interact with, making smart processes, anyway there are some challenges like how could be device's various features manipulated in an easy manner. I strongly believe that the best solution as presented and proved to be working in [3-6], is the RESTful (REST - Representational State Transfer) architecture that's the heart of the web and that will allow seamless integration of various object's features as resources, to combine and meshup applications helping end users in easier integration of new devices. As it was proven in [7-10] REST technology has multiple advantages over WS-* web-services.

On the other hand, the second component that is discussed and interconnected with the previous one is related to smart buildings that are more and more present in our life. Various buildings don't have anymore the status of a "simple" residential destination; they offer besides building's consumption optimization a high level of comfort by helping people to organize their living style, safety and security as mentioned in [11].

This paper describes a system based on wireless sensor nodes that are capable of measuring various parameters in hospitals, homes, or any other environments.

The rest of the paper is organized as follows. Section II introduces some ideas regarding smart building systems and how healthcare devices could be integrated into them. In section III is presented the wireless monitoring system from

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both hardware and software point of view with the main characteristics it has. In section IV are presented the main ideas behind various device's physical features meshup based on web technologies. Section V contains some web technology based GUI to represent received data. Section VI contains the most important and relevant results based on the presented system. Finally, section VII contains some conclusions based on the presented system.

II. SMART BUILDING SYSTEMS

As mentioned before there are numerous advantages that a smart building system can offer inhabitants providing the required comfort and security, interconnection of various devices, home automation and many more. These systems can be located in various buildings like: residential buildings, hotels, retail buildings, schools, industrial buildings and hospitals. Currently, there are many commercial smart building systems that have various features and implement more than 80 standards and proprietary protocols that bounds end-users to a certain manufacturer and technology. Anyway, there are several problems that prevent smart building systems to be widespread, these are: the high installation price, installation complexity and lack of a user friendly control interface.

There are multiple physical communication mediums that smart building systems are using for transferring data, these are the twisted pair cables, Power Line Communication (PLC) and wireless ones. In this paper, I concentrate only on the wireless interface, only mentioning about PLC, both being the dominant interfaces due to the advantages they offer.

Power Line Communication (PLC): it's using the household electrical power wiring as a physical medium and the biggest advantage it offers relies in that it doesn't need any additional control wiring. Communication through PLC systems is made by impressing a modulated carrier signal (between 3-500 kHz for narrowband communication and 1-80 MHz and beyond for broadband communication) on the wiring system. Besides of being a cost-effective solution it has some disadvantages like propagation problems and electrical noise introduced by various devices connected to the mains.

Wireless communication technology: it's intensively used in various systems, it has to have low-cost, low-power, low data-rate and has to transmit data over a long distance and it has to support many topologies like star, tree and mesh. Its advantages rely in being deployed everywhere therefore end users are able to modify the network topology. Those wireless nodes that require a small amount of energy can be powered from energy harvesting modules, too.

To overcome previously mentioned disadvantages regarding price, installation difficulty and lack of a friendly user interface, I developed multiple automation processes that would change those inconveniences and make much easier the interconnection of various devices. Therefore, I will present the smart building systems hardware and software-related issues and solutions.

From hardware point of view, the most important problem is the lack of a simple solution that would offer easy configuration for various devices, therefore the main objective was to separate the communication part from other circuits. The first step was to search for standard connectors that should have an appropriate number of I/O connection pins but in the same time to be as small as possible to be able to place it in very tiny places and to have a very small price. Finally, I picked the SD Cards and Micro SD Cards to be the holder of electronic circuits to deploy Wi-Fi, 6LoWPAN [12], ZigBee, and other protocol based hardware structures that are named Smart RF (SRF) cards. The SRF card is presented in Fig.1.

Each SRF card has an EEPROM memory to store informations, a microcontroller on 8, 16 or 32 bits, RF interface and chip antenna to be used in small places. Each pin can be configured to have various functions according to the software written by manufacturers. Even if there are multiple possibilities for communication protocols as mentioned before I concentrate on the 6LoWPAN that is the embedded version of the IPv6 protocol that provides the opportunity for interconnecting trillions of trillions of devices intro the so-called Internet of Things paradigm. The 6LoWPAN protocol is implemented on a real-time operating system called FreeRTOS that brings multiple advantages compared to event-driven operating systems, besides offering support for multiple platforms it's able to run multiple tasks in the same time, therefore, making various applications to work in real-time.

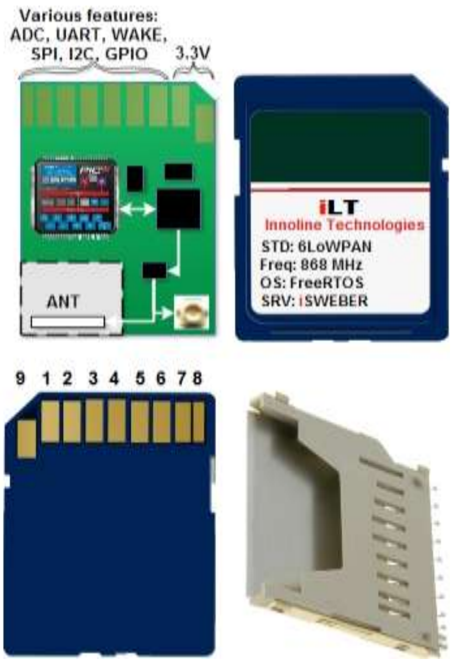

Fig.1. Smart RF Cards

Even if SRF cards have few I/O pins it can be connected to port expanders that could provide multiple communication pins, but generally seven I/O pins are more than enough for the majority of projects, that can be configured as SPI, I2C, UART, ADC, GPIO as presented in Fig. 1.

As mentioned before an operating system is driving the whole device having multiple tasks deserving various applications starting from communication tasks to processing, sensing and actuating tasks.

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III. Remote health monitoring device

In this section I present the wireless healthcare monitoring device from software and hardware point of view. As mentioned before there are multiple health monitoring devices but the majority of these are working standalone not being able to communicate with other devices or to be integrated into some wireless system.

Anyway, lately there have been more and more remote health monitoring devices appearing on the market like Carescape, Onyx, ViiCare, Lifeline, LifeShirt and many others, each one having its properties and particularities, but neither of these supporting dynamic configurations of various features nor having the list of features comparable to features presented in this paper for device named HealthBox. This device can monitor heart rate, blood pressure by using Pulse Wave Velocity, body temperature, respiration rate using accelerometers, oxygen saturation - SpO2, motion activity, location and body posture.

From its design point of view, it has a quite small size. It's wearable, has automatic functions, being able to continuously monitor various parameters in real-time, to work while the end user is moving. It's able also to warn when some problems occur like falling, cardiac disorders or any other malfunction. It has multiple communication possibilities through Bluetooth, Bluetooth Smart, 6LoWPAN or other 802.15.4 based protocol, USB and direct Ethernet connections. The block schematic is presented in Fig. 2 respectively its positioning on the body in Fig. 3.

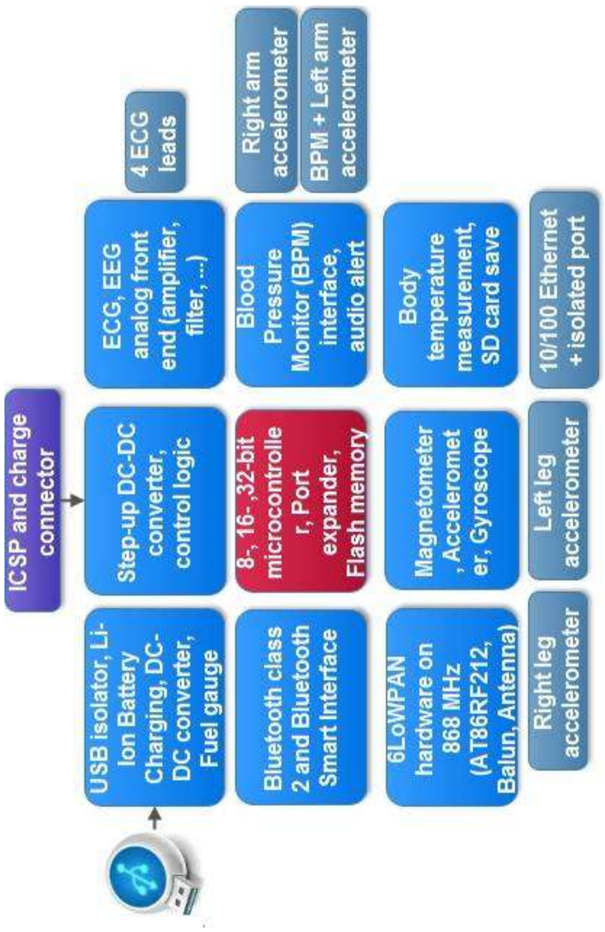

Fig. 2. HealthBox, Remote Health Monitoring device

The whole system is powered from a single high capacity rechargeable Li-Ion battery, that has circuitry to measure charge level and to charge the battery from USB or through its dedicated connector. It's using the SRF Card to establish communication through 6LoWPAN, anyway it's not limited to only this, other protocols could be used while respecting some minimum software requirements. The 6LoWPAN connection is used to overcome various scenarios when Bluetooth's connection to the phone is not available, therefore, being able to transfer data through 6LoWPAN enabled devices to the gateway device that has a wired or wireless connection to the internet as presented in Fig. 4. This construction can be used in hospitals or homes for alerting purposes if some problems occur.

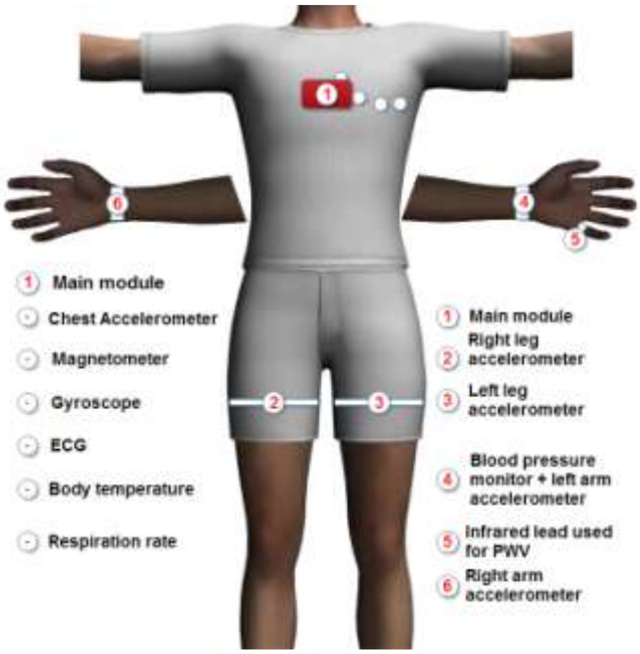

Fig. 3. HeathBox device positioning

There are also other advantages, especially when the entire system is deployed in a hospital in this way it's very easy to find various persons locations in a building or in larger areas, as long as there's a 6LoWPAN network nearby.

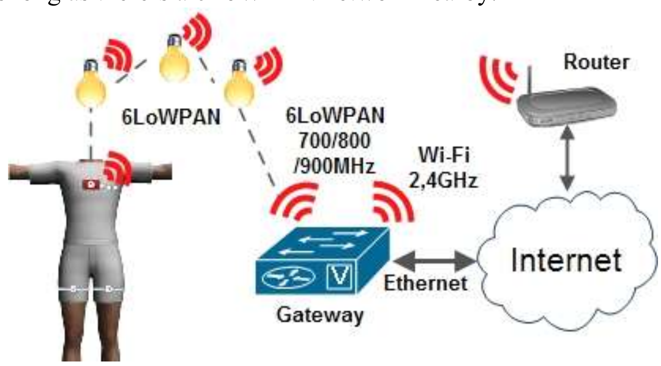

Fig. 4. Connection of HealthBox to 6LoWPAN network

By identifying patients through the healthcare device various other resources could be linked to its identifier like X-ray radiographs or others. It has to be mentioned for not having any problems due to interference with other Wi-Fi devices or Bluetooth devices, I have chosen the sub-GHz frequencies instead of the crowded 2.4 GHz frequency anyway it can be integrated into 2.4 GHz 6LoWPAN network if it's necessary by changing its SRF card.

The healthcare device is using the SRF card only as a data-transfer module through the SPI interface, because it needs more I/O pins that the card could provide. Data transfer is made through the network formed by light bulbs and other devices present in any smart building that has continuous power supply as presented in Fig. 4.

IV. RESTful Architecture for Application Meshup

As outlined in [3, 13] the Web of Things uses HTTP web protocol to provide required interoperability at the application layer to adapt the REST architecture for various device objects as resources using Uniform Resource Identifiers (URIs). Instead of using various proprietary protocols it's much easier to use some freely available ones as the HTTP that through decades proved to be a reliable protocol. The entire interaction is based on a uniform interface where the HTTP protocol provides four methods that help interact with resources. These methods are the following ones GET – to retrieve the representation related to a resource like sensors (temperature, humidity, light, etc.), PUT – used to create a new resource to set various resources like actuators (leds, motors, etc.), POST – used to update a resource state, DELETE – delete a resource.

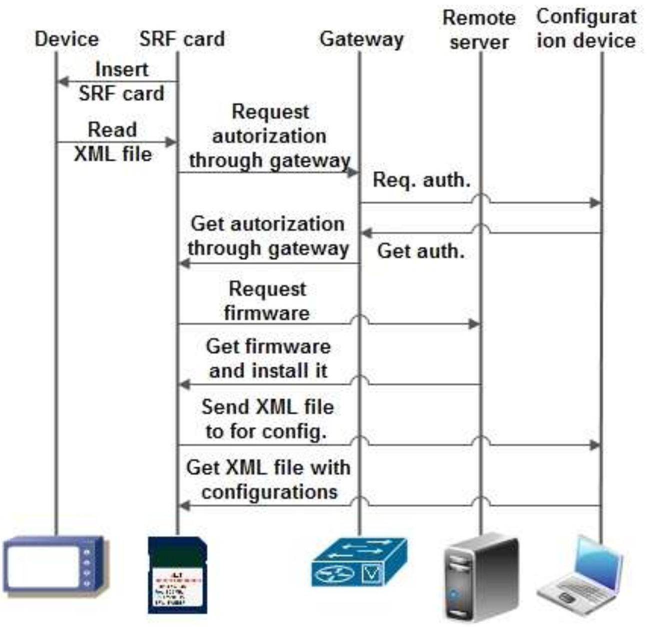

Fig. 5. New device configuration process

A general structure of such kind of URI looks like the following one: *http://<DOMAIN>:<PORT>/floor1/roomx/sd2/actuators/led1*, where a led is accessed that is a resource of a smart device named *sd2* located in the *roomx* on *floor1* having the base address *http://<DOMAIN>:<PORT>*.

Even if the SRF card is 6LoWPAN communication enabled it needs some information about the device that will have to be controlled, therefore it has to read device's EEPROM memory to get the XML file. The entire process of installing a new device is presented in Fig. 5.

The XML file contains all the necessary informations a smart device needs to be integrated into a smart building system. These informations are structured in multiple categories as *<description>* that contains some particularities of the device like manufacturers name, firmware web address, a Unique ID and many other useful informations. The second category named *<connections>* will be filled up with multiple data related to different connections with devices due to the fact that there are various scenarios when a sensor has to send a certain value to multiple devices. The third category named *<URIDesc>* and being split in two sub-categories *<actuators>* and *<sensors>*, contains the description of various objects as resources, the URIs.

There are other possibilities to make various devices integration into a smart building system as easy as possible. The second possibility implies the use of a mobile phone to identify QR codes as presented in Fig. 6, that could contain the address to the firmware and to the XML description file, anyway it's downloading path will be through the gateway device. The third possibility would be the use of some extra hardware to be able to read RFID tags attached to various devices. For the second solution, a Near Field Communication (NFC) enabled smart phone could be used as presented in Fig. 6. The download path is the same like in the previous solution.

Fig. 6. QR Codes and RFID Tags based device identification

Even if there are multiple solutions for device identification for now I've chosen the flash memory based solution that has the XML file, this solution being more straightforward.

V. Web Solution for Data Presentation

As long as the Web of Things relies on HTTP protocol and adapts the RESTful architecture it's easy to make applications that could run in any browser. The most important step after connecting a new device to the system, in this case a healthcare device, is to meshup various device features, process that will be explained in the following paragraphs.

To be able to get informations from the device in the first step the XML file has to be read that contains the most important informations like general data and URIs for objects. After getting the list of features end-user would be able to assign various processes, where could be specified what informations should be sent at which device and how should it be formatted. After making the necessary settings the entire list of connections will be saved within the XML file and rewritten into the device EEPROM memory as well as a copy to the gateway for fast data access and availability in case the SRF card is changed to be able to refresh new card's connections list, not having to remake the meshup process.

After the meshup process is ready than various data will be sent between different devices according to specified rules. To check various parameters of HealthBox device end-user has to know only the respective URI, that will help to read desired resource. Anyway it's very difficult to know all the features a device has and to remember all the URI or to select them from a list without having the proper user friendly interface therefore extension packages can be downloaded from device's URL that would contain a very rich user interface with all necessary URIs and graphical elements like pictures and graphs. This is very important because the new HTML5 will bring many advantages to be able to make more interactive interfaces. Such kind of GUI is presented in Fig. 7.

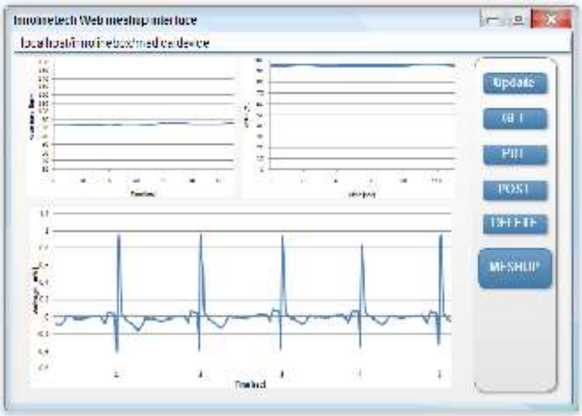

Fig. 7. Web page containing graphical elements to present data

The biggest advantage for end users is the fact that they will be able to use various interfaces anywhere by using a simple web browser.

VI. Evaluation

For the evaluation purpose I used a system made of the medical device, two light bulbs for data forwarding respectively a gateway device connected to the internet through an Ethernet connection. Connection to control devices for making the meshup process is made through an Ad-Hoc Wi-Fi interface using the gateway device as presented in Fig. 4. The flash memory present on the HealtBox was previously programmed with the XML file containing the most important informations like the URIs to various objects and some basic informations about the device.

After mounting the SRF card into the medical device's socket, the operating system get initialized, started the web server and sent a registration request to the gateway device through 6LoWPAN environment that had been forwarded to a computer through a Wi-Fi interface.

As long as the gateway device had its own control interface it showed up a request with the minimal informations from the XML file contained in the medical device memory with the purpose of authorizing device installation. After this process based on the firmware address pointing to the http://www.innolinetech.com/firmware/HealthBox_20120912_766321938, where the ID contains the date, and a unique ID, the firmware was downloaded into SRF card memory and installed into the microcontroller.

The next step was to meshup various features like the fall detection and alarming part, that was set to send a alarm signal through Bluetooth for the currently paired device or if it's not available than through the 6LoWPAN interface. The rest of the settings and visualizing interface was downloaded from the server that contained all the necessary file to be able to represent various informations, like battery charge level and many other readings that the medical device was capable of. After the meshup process, a copy of the XML file was saved into the SRF card and a second one into the gateway device for fast access for future configuration, not having to reread each device's XML file.

Measurements were made with the medical device mounted on a person's chest, being in a sitting position.

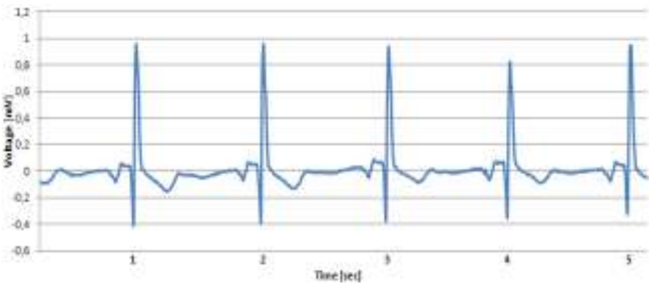

Fig. 8. ECG readings from HealthBox

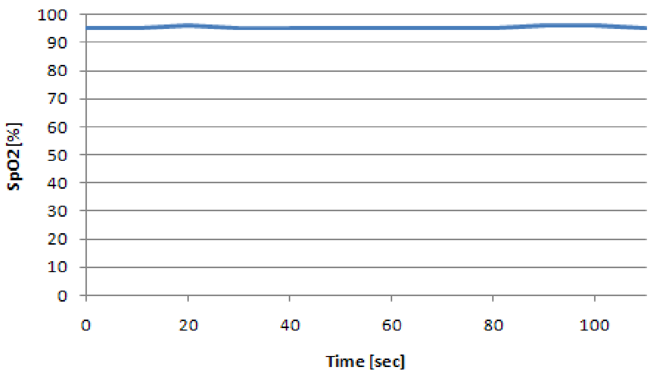

Fig. 9. Blood oxygen saturation level readings from HealthBox

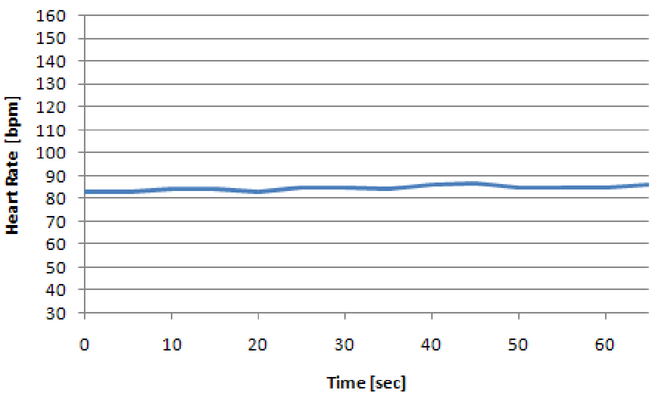

Fig. 10. Heart Rate readings from HealthBox

Three parameters were measured: the first one is the ECG presented in Fig. 8, the blood oxygen saturation level presented in Fig. 9, that shows that it has a value over 95% that’s an optimal value. The last asset values that were read out from the medical device is the heart rate presented in Fig. 10. that has optimal values, too.

VII. Conclusion

Based on described healthcare system, I can conclude that the presented hardware and software solutions are among the best ones due to advantages that each part is providing. The SRF card can bring required flexibility to the system, end users being able to decide what communication tools should be used not to be bound to certain companies. The configuration process is very easy; therefore, the majority of end users will be familiarized with the configuration environment since it’s based on popular web browsers that can be found for each platform and are used daily by end users. In the back of the meshup process, everything works automatically based on the web server that is present on the SRF card. I strongly believe that this technology will bring required flexibility for smart building systems and acceptance by end users and manufacturers for its easy handling and configuring profile not having to deal with complicated protocols and pay much money for various hardware.

Anyway, there are lots of things to do, by porting the FreeRTOS to as many platforms as possible in order to be able to choose the best one for certain purposes. Besides the SD Card other hardware support can be used like USB connection enabled modules for high data rate transfers. SRF cards can be made to support Bluetooth, Bluetooth Smart, Wi-Fi or any other protocol maintaining the simplicity of configuration.

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