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Solutions for Healthcare Monitoring Systems Architectures

1st Mohammed Tali Almalchy
University Politehnica of Bucharest
Bucharest, Romania
almalky.leader@gmail.com

2nd Vlad Ciobanu
University Politehnica of Bucharest
Bucharest, Romania
vlad.ciobanu@cs.pub.ro

3rd Sarmad Monadel Algayar
University Politehnica of Bucharest
Bucharest, Romania
sarm.moon85@gmail.com

***Abstract*—The overall goal of a complex wearable healthcare monitoring system (WHMS) is to support design and development a high impact personalized ICT healthcare services based on measurements of health state acquired by sensors capturing everyday physical, cognitive and social activities of that will be fed into the risk prediction model to perform personal profiling and identify deviations from the expected baseline of each specific user groups. In this paper, a robust comparison of different solutions of architectures dedicated to Wearable Health Monitoring Systems (WHMS) based on microcontrollers and FPGAs are presented and analyzed. It is also proposed a new architecture that uses all the advantages of its components. An embedded microcontroller will facilitate the communication. An eHealth specialized platform like MySignals Hardware Development Platform V2.0 will be used for recording and analyzing the data coming from the medical biosensors. For a critical analyze of the current state of the art, a set of relevant research papers will be reviewed.**

Keywords—healthcare monitoring system, medical biosensors, eHealth board, microcontrollers

I. Introduction

Nowadays, the overall goal of a complex wearable healthcare monitoring system (WHMS) is to support design and development a high impact personalized ICT healthcare services based on measurements of health state acquired by sensors capturing everyday physical, cognitive and social activities of that will be fed into the risk prediction model in order to perform personal profiling and identify deviations from the expected baseline of each specific user groups (e.g. older adults). An ideal WHMS should create know-how on manipulating sensed user data and on provision of personalized advices for an individual's health condition and guidance for daily life activity, emphasizing on the ability of a person to maintain its independency, healthy lifestyle, risk avoidance and a general wellness. The goal of such a system is to preserve physical, mental and cognitive well-being.

Over the past decade, technology solutions to monitor and improve health have become more and more enforced. They refer both to monitoring the health of people under medical supervision and to interacting with doctors or assistants working in clinics or at patients' homes. Thus, technology can facilitate communication between these groups, acting as a binder between patients and the professional communities involved, both in prevention programs and in tracking a patient's evolution. When talking about eHealth, we also refer to complex event processing, eHealth innovative services, big medical data management, real time remote patient monitoring and health-related rumor spreading events detection.

Complex event processing is dealing with the efficient processing of huge amounts of the real-time data, with the main goal to detect so called situations of interest, represented as complex event patterns, as early as possible (business real-time). Currently the focus is on the efficient algorithms for the pattern detection, enabling very fast processing of hundreds of thousands of (rather simple) events [1]. However, new scenarios are requiring ever more sophisticated processing to realize advanced detection in the heterogeneous data streams. Some examples are: processing of uncertain information, semantic processing, processing of unusual situations and proactive pattern detection.

One of the most challenging feature of a WHMS should be related to the new services for detection of unusual situation in the huge heterogeneous streams. These services will support the definition, detection and management of unusual situations in order to satisfy the need for dealing with highly changing environment future internet applications are working in. Indeed, a very high variety in the data streams coming from the mobile sensors (IoT in general [2], [3]) will require in intensive changes in that what can be interesting to be detected, resulting in the need for detecting non-standard situations/anomalies.

The wearable healthcare monitoring systems consists of different types of biosensors. These sensors measure medical parameters like blood pressure, temperature, electrocardiogram (ECG), oxygen in the blood, muscle electromyography (EMG) and other physiological aspects related to a patient. All the data coming from the medical sensors are aggregated and sent to a unit called PMU (Portable Monitoring Unit). The processed data will be transferred to its destinations.

There are yet many challenges in making the wearable healthcare monitoring systems more applicable to the real-life having important features like reliability and multi-functionality. Designing and development of a perfect wearable monitoring healthcare system (WMHS) that really improves the quality of life is very challenging.

The paper is structured in 6 sections. After the introduction, Section 2 presents the wireless communication modules adequate for a WHMS, Section 3 discusses relevant information related to the medical biosensors involved in such a health care monitoring architecture, Section 4 offers a robust analyze regarding the FPGA and microcontroller-based devices suitable for WHMS and Section 5 describes a solution of architecture and a case study based on the approaches discussed in the previous sections. Conclusions offers the final remarks and some observations.

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II. WIRELESS COMMUNICATION MODULES FOR WHMS

The way in which data coming from the medical biosensors are transmitted has been careful analyzed and a design of the main transmission sections are further discussed and presented in Fig.1. The transmission is realized on three different sections. The first one is the short-range communication, here data is gathered from the biosensors and sent to the PMU in a wired or wireless way. The second section is also short-range communication and regards the communication between PMU and the devices handled by medical stuff (PDAs, smartphones). The third section (long-range transmission) sends the data from PMU to the remote medical.

The most widely used wireless communication modules in health monitoring systems are the ZigBee 805.15.4 [4, 5], Bluetooth 805.15.1 [6], ANT+ [7] and NFC [8, 9].

III. MEDICAL BIOSENSORS

The medical biosensors are very important in maintaining high score parameters for safety and effectiveness of medical devices. Several biosensors can be utilized in the wearable healthcare monitoring systems to be part of the BAN. They measure the physiological signals of the human's body and transfers them to the central node. The biosensors that were considered in this research are:

- blood pressure sensor - It measures blood pressure offering two values: the systolic pressure (meaning the heart beats) and the diastolic pressure (representing the phase when the heart relaxes between beats).
- electrocardiogram (ECG) sensor - The sensor used to assess the electrical and muscular functions of the heart.
- electromyography (EMG) sensor- Detects the electrical potential coming from muscles when the muscular cells are activated electrically or neurologically. The signals can be analyzed to determine certain abnormalities or to investigate the biomechanics of body movement.
- electroencephalogram (EEG) sensor - Measures the of electrical potentials of the brain.
- pulse oxygen (SPO2) sensor - Oxygen saturation represents the amount of oxygen dissolved in the blood, based on the detection of Hemoglobin and Deoxyhemoglobin. Usually this sensor measures the heart beats too
- glucometer - determining the approximate concentration of glucose in the blood.
- body temperature sensor - The temperature sensor measures the human body temperature with a very small deviation (max. 0.1 ºC).
- body position sensor using an accelerometer - This sensor determines the body position according to triple axis. In this way it can be identified if the patient stands, sits, changed his position up, down, left or right.
- airflow breathing sensor - The nasal / mouth airflow sensor is a device used to measure the breathing rate and is mandatory for emergency cases when a patient needs help for respiration.
- Spirometer air capacity sensor – a measuring device that measures the pulmonary functioning by means of some parameters correlated to the maximum possible exhalation and the forced expiratory volume in 1 second.
- snore sensor - records vibration and the sounds of snoring converting them to small analog voltage.
- GSR galvanic skin response sensor - This sensor measures the electrical conductance of the skin that depends on its moisture level. It is influenced by the emotions that body scale sensor - This sensor measures the weight or calculate mass. It uses a BLE connection to synchronize your weight and body fat values with the health dashboard of a patient. The measured parameters can be not only the weight but also the bone mass, body fat, body mass index or muscle mass.

For development of medical applications, some shields and

boards dedicated to eHealth systems have been used in the last years. One of such platform is MySignals launched by Libelium and represents a robust solution for medical applications that gather data coming from biosensors, being very useful in developing your own eHealth web, Android or iOS applications.

IV. FPGA AND MICROCONTROLLER-BASED DEVICES SUITABLE FOR HEALTHCARE SYSTEMS

In healthcare domain, the FPGA architecture and Arduino architecture (as a type of Microcontroller) have gain important roles, many eHealth systems being based on them. This section attempts to review several research prototypes on wearable biosensor systems for health monitoring based on FPGA and Microcontroller and also to

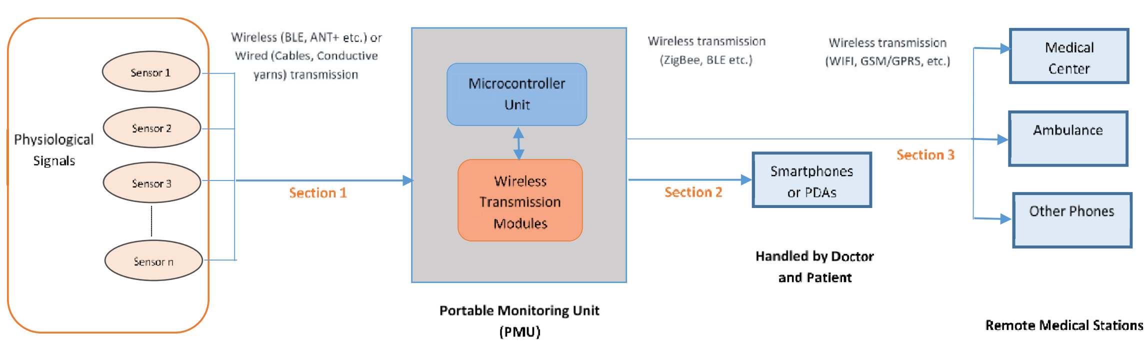

Fig. 1. Data transmission solution for a Healthcare Monitoring System.

highlight some fundamental concepts in both approaches that make them appropriate for eHealth applications. Field programmable gate arrays (FPGAs) are semiconductor devices that can be electrically programmed in the field to become almost any kind of digital circuit or system. FPGAs are manufactured by companies like Xilinx, Altera, and Actel etc.

On the other hand, several industrial microcontroller platforms are available in the market which can be used to build healthcare systems. Choosing a certain microcontroller platform (Intel Galileo, ARM7 LCP 2148, Arduino Uno Rev.3 or the Raspberry Pi board) should be done after a proper analyze of their features to correspond to the requirements of a robust Wearable Wireless Healthcare Monitoring System (WWHMS).

A lot of research on healthcare using FPGSs have been done. Bhelkar and Shedge [10] used three sensors: Heartbeat sensor, LM35 sensor and Accelerometer ADXL355 for monitoring the parameters heartbeat, temperature and motion to develop health monitoring device for patient based on FPGA. The graphical user interface (GUI) has been developed by using programming language visual basic and the collected data from the sensors is forwarded into GUI so that the patient will be able to see the parameter values. The SMS and Email systems has been used in case of any emergency. The system was useful for patients, doctors and medical recording. The FPGA has been utilized in this project instead of microcontroller because it is reconfigurable and necessary hardware can be added as and when required.

Kumar et al. [11] proposed a design and model of a Wireless Sensor Monitoring System by using FPGA. This system can integrate it with other technologies or infrastructures with low cost. The remote short-range communications have been used in the wireless system. VHDL was used to perform the required FPGA functions such as bus data buffering, interfacing, compression and data framing. Compressing stored data with the use of RLE was so efficient. The real-time simulation for both Simulink and VHDL models was not the main goal of this work, but it was to build a pragmatic design and suitable for future hardware design. The FPGA modules have been verified and implemented by using Xilinx Spartan-3 device. The main motivation behind using the FPGA device to execute the digital part of the model was to have a ready platform for ASIC (The next stage of this research work) as well as the FPGA is configurable and so can be upgraded at any time.

Ravinder et al. [12] prepared "A Novel Wireless Biomedical Monitoring System with Dedicated FPGA-based ECG Processor". The system gives a portable and real-time ECG monitoring system featuring HRV analysis and used Bluetooth module to transfer the data wirelessly based on the development platform System-on-Chip (SoC) FPGA. This system was presented to show it as a proof-of-concept design for the ECG monitoring system.

Felix et al. [13] worked on "Zigbee based Wireless Patient Monitoring System using FPGA". This project was developed to observe two medical parameters the body temperature and hearth beat rate of the patient remotely and send the measured rate to the doctor through GSM Protocol. As well the system gives the patient the ability to control the room devices such as fan, light and TV from the bed itself by using the Bluetooth technology. In this system parallel communication is possible and efficiency increased by using FPGA Spartan 3E. Girish et al. [14] prepared "Wireless real-time health monitoring system built with FPGA and RF networks", In this project, a real-time ECG monitoring system has been designed by featuring HRV (Heart Rate Variability) analysis and wireless data transmission through radio frequency based on a System-on-Chip (SoC) development platform. The Xilinx ISE and Modalism Xilinx Edition (MXE) utilized a simulation and synthesis respectively. The FPGA has been tested with used of Xilinx Chipscope tool inside results while the logic running on FPGA. In this work the Xilinx Spartan 3E Family FPGA development board has been used to give a real-time monitoring and also it can play multi-functions, including control, filter, and system. The ECG FIR filter design method based on FPGA, where we can see the results of high-frequency and 50Hz power-frequency interference dual filters. the filters were used directly in FPGA embedded ECG monitor design, ECG monitor system to collect, playback, store, and the wireless transmission was integrated into a FPGA chip, so that could reduce the development of analog circuits, reducing development costs, research, and design cycle. We could see the filters had a good application value.

Speaking about Arduino approaches, Sowmya and Sandeep [15] developed a remote healthcare monitoring system using Arduino board over distributed ubiquitous environment. This system embeds a message passing framework to the device based on the sensor data variation. The framework consists of three segments such as Arduino Uno (ATmega328P), GSM modem, Pulse rate sensor (Ear clip Heart rate sensor) and temperature sensor. The processed data is sent from the microcontroller to the server where MATLAB programming is implemented to read data from the server. This system aims to improve the everyday life of patients experiencing unending heart diseases, by observing any cardiovascular occasions changing. As well as it will enhance the nature of social insurance division.

Monicka et al. [16] proposed another ubiquitous based system for healthcare monitoring. This system consists of three main units are data acquisition unit, data processing unit and Data communication unit. All interact with each other to provide real-time monitoring, processing and reporting. The Arduino analyses the data in real-time from the sensors that attached on the patient's body which are Pulse sensor, Glucometer sensor, Body Temperature sensor and heartbeat sensor and then determines whether the patient needs external help by offering suggestions based on the processed data. After the data is processed, a SMS alert is sent to the patient, doctor or ambulance according to a Threshold value in an emergency. The local database is created with the use of MYSQL. Fundamentally, the aims of this work are to improve the patient's health, reduce in hospitalization and assistant cost.

The research of Shivwanshi et al. [17] also focused on the design and development of Wireless Sensor Network for Biomedical Application. A motion sensor device has been developed in this work where this single sensor can be utilized for various applications by using it at different time periods such as monitor rehabilitation exercise, step counting, sleep tracking, and estimation of burned calories.

In this model used 3-axis accelerometer, Arduino microprocessor (ATmega-328p) and Bluetooth HC-05. This device needs 5 v power supplies to run it in proper active mode. The system can transfer the signals properly within the range (5-10) m. This work shows that the small and lightweight sensor module can serve multiple applications with high accuracy.

After this careful literature review, a discussion underlines the following aspects mentioned below.

Each of the Arduino, Intel Galileo and ARM7 LCP2148 are Microcontrollers and it doesn't have an operating system, you have to upload the program from a computer via USB and that program runs each time you switch it on. While the Raspberry Pi is a small single-board computer runs with the Arduino has less speed than the others, it is more suitable for controlling sensors. As it was seen in the articles [15, 16, 17], utilizing Arduino in the healthcare systems using several biosensors could give accurate results. So, Arduino could cover the most requirements of the proposed system.

An embedded microcontroller is always necessary to support the interaction between any device and the computer and to facilitate the communication. The most important difference between a microcontroller and an FPGA is that the microcontroller structure is almost analogous to a simple computer placed on a single chip with all the necessary components such as the memory and timers embedded internally. The microcontroller is basically programmed to do some simple tasks for other hardware. Whereas the FPGA is an integrated circuit that could consists of millions of logic gates which can be configured electrically to perform a particular task.

A Field Programmable Gate Array or FPGA does not have a constant structure. It can be programmed according to the user applications. Naturally, the FPGA is more flexible than most of the microcontrollers. The FPGA can be reprogrammed to do any logic task, any design being transformed to several gates (combinational logic blocks). In the case of a microcontroller, it has its own circuitry and instruction set that the programmers must follow to write codes for that microcontroller. Some restrictions are imposed to implement tasks.

FPGA consumes more power than typical microcontrollers, and this is the reason that makes it inappropriate for applications where energy depletion is an issue. In order to write an FPGA function in a particular role that would also take longer time compared to microcontrollers because in one function needs to write all the code from scratch and then convert it to a machine language. Whereas with microcontrollers, we can buy packages that are prepared for a certain task and it just needs to be programmed to our exact specification relatively rapidly.

Another aspect that should be considered are the advantages/disadvantages of programming in Hardware Description Languages ((Verilog, VHDL) in the case of FPGA versus the programming languages for microcontrollers: C, C++, C#, etc.

V. Wearable Health Monitoring System Architecture

As a result of the above discussion, research and analyze, this section presents a solution of the design for an architecture dedicated to a Wearable Health Monitoring System. A scenario will be also described and discussed.

The information from 6 sensors is recorded and analyzed by MySignals shield [18]. Due to the decision module implemented on Arduino, all the values of the parameters that exceed a certain range are sent real time to the application running on the doctors' smartphone. The doctor will be able to monitor the parameters in two different communication modules, short-range communication (ZigBee) and long-range communication (GPRS/GSM). First, the doctor can have a real-time and direct monitoring when he is available within the coverage area of the ZigBee signal (inside the hospital). Second, in case a patient is outside the hospital, in another word, if the ZigBee signal cannot be reachable by a doctor then all the values of the parameters that reached the threshold will be sent real-time to the doctor's smartphone through SMS.

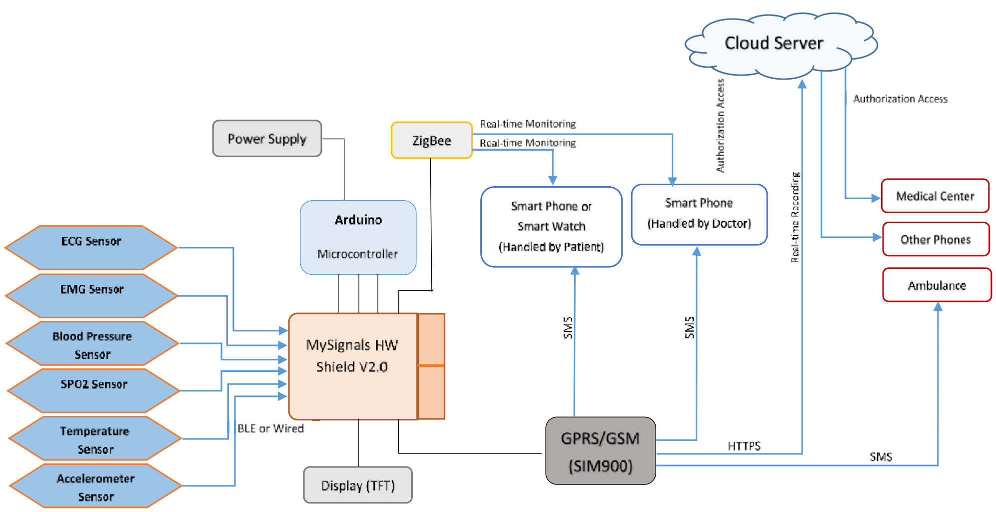

Fig. 2. Proposed Solution for a Healthcare Monitoring System Architecture.

The GPRS/GSM (SIM900) shield will be used in the system to transfer the data from MySignals HW and store it in the cloud database. Advanced algorithms will be implemented in Arduino microcontroller for decision making where the threshold values will be sent real-time to the patient, doctor, and ambulance according to the threshold values emergency. For instance, in case the blood pressure rate for systolic (upper) is (120-139) mm Hg or for diastolic (lower) is (80-89) mm Hg then SMS will be sent to the patient's smartphone as an alarm; warning him for taking precaution. And if the to the doctor's smartphone so that he takes an immediate treatment to prevent the situation from worsening. And in case the blood pressure rate of the patient is critical like if the systolic (upper) blood pressure is (160) mm Hg or higher \ for diastolic (lower) is (100) mm Hg or higher, then the SMS will be send to the ambulance where the ambulance can detect the patient's location from the GPRS of portable wearable system of the patient, so that they can send him immediately to the hospital to save his life. All the values used in this example have been taken from a book for practice in medicine [19].

The architecture has a cloud component. This means that the proposed solution has all the advantages of handling as many tests as necessary, running software, collaborate with other systems and expand storage if necessary. The cloud computing infrastructure can be considered as a service that bring significant benefits like agility and scalability. The doctor will write diagnosis and prescriptions from the application that runs on his smartphone according to information that he received from the patient's system and then save it in patient's profile in the cloud database. The medical information of the patient that is stored in cloud database will be accessible by specific people who have the authorization to access such as patient himself, doctor, patient's family member, etc.

The transferred data among system components will be encrypted by security protocols to protect it from any malicious acts of the hackers. Fig. 2 is showing the proposed system architecture.

VI. Conclusions

In developing a robust healthcare monitoring system, different solutions should be carefully analyzed. Because one of the most challenging feature of a WHMS should be related to the new services for detection of unusual situation in the huge heterogeneous streams, these services should support the definition, detection and management of unusual situations that can appear in a medical and healthcare environment.

For this reason, the paper discusses different solutions of architectures dedicated to Wearable Health Monitoring Systems (WHMS) based on microcontrollers and FPGAs. A comparison based on these approaches was also introduced. The literature review revealed the fact that in healthcare domain, the FPGA architecture and Arduino architecture (as a type of Microcontroller) have gain important roles, many eHealth systems being based on them.

This kind of WHMS offers solutions for bringing improvements in healthcare field by offering a many feature that bring comfort, care and safety to a patient. Such a system should be lightweight, robust and portable, maintain the privacy of the patient and collecting important medical information that will provide a better treatment by a real-time monitoring. To achieve all these requirements, the research focused on studying and analyzing many aspects to resolve most of the challenges. A solution for the wireless communication modules of WHAS was presented and discussed. This is a work in progress and a future stage will consist of the healthcare monitoring system implementation starting from these analyzed requirements.

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References

[1] O. Etzion and P. Niblett, “Event Processing in Action”, Manning Publications, ISBN: 9781935182214, 2010.

[2] A. Garai, A. Atila, I. Pentek, “Cognitive telemedicine IoT technology for dynamically adaptive eHealth content management reference framework embedded in cloud architecture”, In Proceedings of 7th IEEE International Conference on Cognitive Infocommunications , Poland, 2016, pp. 187-192.

[3] U. Celentano; J. Röning, “Framework for dependable and pervasive eHealth services” In Procedings of IEEE 2nd World Forum on Internet of Things (WF-IoT), 2015, pp: 634 – 639.

[4] ZigBee Alliance, Web: http://www.zigbee.org/ , Accessed in April 2018.

[5] S. Dagtas, G. Pekhteryev and Z. Sahinoglu , “Multi-stage Real Time Health Monitoring via ZigBee in Smart Homes”, Mitsubishi Electric Research Laboratories, 2007.

[6] R. Bouhenguel, I. Mahgoub, and M. Ilyas, “Bluetooth security in wearable computing applications,” in Proc. Int. Symp. High Capacity Opt. Net. Enabling Tech., 2008, pp. 182–186.

[7] "ANT+", Available at: https://en.wikipedia.org/ , Accessed: April 2018.

[8] N.N.K. Razmi and A.B. Sangar, “The Use of NFC Technology to Record Medical Information in Order to Improve the Quality of Medical and Treatment Services”, Canadian Center of Science and Education, 10(6), 2016, ISSN 1913-1844 E-ISSN 1913-1852.

[9] V. Gunjan and V. Ukalkar, “Survey on NFC in Healthcare Sector”, International Journal of Innovative Research in Computer and Communication Engineering, 5(2), pp. ISSN(Online): 2320-9801, ISSN (Print): 2320-9798, 2017.

[10] V. Bhelkar and D.K. Shedge, “Design and Implementation of Health Monitoring Device using FPGA”, International Journal of Computer Applications, 158(7), 2017, pp. 0975 – 8887.

[11] N. Sudheer Kumar, A. Sateesh Kumar, V. Satish Kumar, “Wireless Sensor Monitoring System by using Field Programmable Gate Array(FPGA)”, International Journal of Engineering Research & Technology (IJERT), 3(1), 2014, pp. 2278-0181.

[12] K. Ravinder, M. Irfan-ur-Rahman, M.W. Hussain, M. Abdul Khader, A. Mohiuddin, “A Novel Wireless Biomedical Monitoring System with Dedicated FPGA-based ECG Processor”, International Journal of Advanced Research in Computer and Communication Engineering, 2(12), pp. ISSN (Print): 2319-5940, ISSN (Online): 2278-1021, 2014.

[13] L. Arul Leo Felix, A. Arockia Faustine, D.Sellathambi, “Zigbee based Wireless Patient Monitoring System using FPGA”, International Journal of Innovative Research in Computer and Communication Engineering, 4(4), pp. ISSN(Online) : 2320-9801, ISSN (Print) : 2320-9798, 2016.

[14] P. Girish, B.V. Ramana, G.M.V. Prasad, S.V.S.M. Madhulika, “Wireless real-time health monitoring system built with FPGA and RF networks”, International Journal of Research in Computer and Communication Technology, 3(11), pp. ISSN (Online) 2278- 5841 ISSN (Print) 2320- 5156, 2014.

[15] G. Sowmya and B.L. Sandeep, “Remote HealthCare Monitoring System Using Arduino Board Over Distributed Ubiquitous Environment”, International Journal of Advanced Research in

Computer and Communication Engineering, 5(4), pp. ISSN (Online) 2278-1021, ISSN (Print) 2319 5940, 2016.

[16] S. Monicka, C. Suganya, S.N. Bharathi, A.P. Sindhu, "A Ubiquitous Based System for Health Care Monitoring"", International Journal of Scientific Research Engineering & Technology (IJSRET), 3(4), 2014, pp. 2278 – 0882.

[17] R.R. Shivwanshi, C. Ahuja, P. Abrol, B. Singh, "Design and Development of Wireless Sensor Network for Biomedical Application", Advances in Computing, Communication, & Automation (ICACCA), DOI 10.1109/ICACCAF.2016.774898, 2016.

[18] "MySignals HW ", Available online at: https://www.cooking-hacks.com/, Accessed: April 2018.

[19] B. Walker, N.R. Colledge, S. Ralston, I. Penman, "Davidson's principles and practice of medicine", 22nd ed., ELSEVIER: General Medicine, 2014.