Low-Power Design and Implementation of Embedding Electronics for Telemedicine Mobile Applications

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Abstract**-- Medical sensors nodes are capable of sensing, processing, and communicating vital signs, can be seamlessly integrated into wireless body networks (WBNs) for health monitoring. In This paper, the proposed architecture of the embedding electronics for telemedicine system based on mobile applications is presented. We covered most system requirement needs as portability, simplicity, easy to use, and low cost. It composes of 3 levels: Level-1: The application Platform for Data Processing: is supported by Android based operating system is used for monitoring the readings from the physical world into electrically defined signals in order to use these signals to map the readings to our core board. The processing phase consists of three algorithms for measuring Heart rate and Body temperature independently from patient's body, process those readings, and submit them to tailored developed database related to patient profile. The specialized doctor can remotely examine and diagnose the patient's condition remotely and efficiently.**

Level-2: The data Communication and Sensor nodes which composed of Central Control ADC module and sensors (level-3) are connected via wired connection, it is communicating with smartphone (level-1) using USB or via Bluetooth connection. Level-3: The data acquisition (Biological Sensors): they produce voltage (digital signal) that is indicative of physical variable they measure. Those signals are often imported into computer programs, stored in files, plotted and analyzed on computers and mobile applications. Unit (CCU) interface and Communication with sensors. In this phase the processing unit samples analog values from sensors through Analog to Digital Converter module (ADC) and send through Bluetooth connection based on serial communication between processing unit and Bluetooth module. The developed integrated system is efficient with respect to portability since it is a one sensors node, cost effective regarding the electronics components used, low power consumption which cover more than 25 hours with small power bank, and finally with efficient UI through a simple android mobile application.

Index Term**-- Embedded systems; Telemedicine; Sensor node Data acquisition; healthcare monitoring; Wireless Body Sensor Networks (WBSN); Analog Digital Converter ADC, Medical Electronics.**

1. Introduction

Telemedicine is forming new structure in healthcare services, using information and communication technologies, the healthcare professionals in specialized fields, such as cardiology, urology, oncology, surgery and others, can access or exchange information for diagnosis, treatment and prevention of disease. This new age concept also provides solutions for continuing education and research among healthcare providers to improve the health of individuals and their communities [1]. Thus, telemedicine facilitates the right medical advice at the right place at the right time using new computer-based communication technologies for medical purposes. Wireless sensor networks of small devices equipped with sensors, microprocessor and wireless communication interfaces, are the technology that has gained a lot of interest lately. The broad spectrum of new and interesting applications, ranging from personal healthcare to environmental monitoring and military applications are proposed for such networks. The proposed system consists of main four parts: Circuit design, Platform architect, Communication protocol established and Sensors network configurations. Taking advantage of telecommunication, medical electronics and information technologies, telemedicine acts as potential source to reduce healthcare expense, improve healthcare service in remote areas and support modern home healthcare and so on. Recent works in communication technologies have inspired the development of telemedicine to a large extent. The common problem was faced during the development of telemedicine system is how to integrate the existing techniques to meet the requirements of telemedicine applications [2-3].

2. Building wireless sensor networks

Wireless sensor networks (WSN) combine three basic features in single system: sensing, processing, and wireless communication. The idea is not only to measure physical quantity, but also to process this real world data locally and to send gathered information to interested entities [4-6]. All of these functions are kept in single device called "Sensor node". The main components of sensor node are microcontroller, memory, sensors, actuators, power supply, transceiver and antenna. There are several prototypes for sensor nodes available today. Most of them are for generic use, i.e. they can be adjusted to different types of application scenarios. The common focus of these devices is that nodes need to be tiny and cheap.

3. Analysis and comparison for the common Telemedicine systems

In the table I below a summary about some telemedicine studies in the last decade along with aspects which each study concern [8]. It indicates what the lacks of a related work by analyzing the state-of-the-art, and how we fill in these lacks.

From these studies no one included all features in one system since we implemented the 3 measured quantities, Temperature, Heart rate and ECG in one package, processing the data, sending wirelessly to mobile then to the repository on the internet. Next section will illustrate our system structure and components. This system design meets the new era of Internet of thing (IoT) since most of devices will be connected across sensors and through the internet to each other and to management console

Table I
Set of telemedicine studies along with aspects which study concerns.

Ref. no.	Bio-signal sensors	Communication technology		Medical algorithm	Comments
		GSM/ GPRS	Internet		
[8]	ECG, BP, HR TEMP.	√	√		WSN, type of localization method for patients and an energy efficient transmission strategy, video streaming.
[9]	HR, SPO2, TEMP., RESP.	√			Implement a prototype of telemedicine system based on wireless technology using GSM and GPS.
[10]	Weight, activity, BP	√	√		Android application for monitoring and using Bluetooth enabled sensors.
[11]	BP, HR, TEMP.	√	√		Design of sensors to reduce power consumption using VLSI and FPGA.
[12]	ECG, HR, SPO2, TEMP., RESP.		√		Wearable belt; high quality and flexible modules for signal conditioning are designed and assembled together.
[13]	ECG, BP, HR TEMP., PPG		√	√	Small rang RF transmission, smart wearable vest, deriving BP and HR from ECG.
[14]	ECG		√	√	QRS detection algorithm, extraction of heart rate variability, implemented in the PDA and GPS.
[15]	ECG	√	√	√	A real-time ECG classification algorithm, GPS, and a real-time R wave detection algorithm.
[16]	Pulse signal		√	√	Intelligent data analysis scheme to diagnose abnormal pulses for exploring potential chronic diseases.
[17]	ECG, HR, SPO2, TEMP., RESP.		√		Vital signals are acquired from the monitor using the RS232 interface and transmitted through the internet.
[18]	ECG, BP, HR TEMP.	√	√	√	Commercial monitors are used for the acquisition of biosignals and Huffman algorithm for ECG signal compression, GSM, GPRS, POTS, or satellite.

4. ANALYSIS OF THE PROPOSED SYSTEM ARCHITECTURE:

Proposed system Objectives: The presented system in this paper is targeting to implement simple, practical, low cost, low power consumption, portable embedding electronics system for vital human signs based on mobile application which has a high penetration rate - around 30% of mobile users in Egypt - to be used in rural areas when the professional specialized doctor is not available all the time and for emergency cases and also for homecare telemedicine services.

The proposed system is composed of 3 levels as shown in Fig 1:

1. Level 1: Data Processing: A mobile-based application for managing and monitoring the readings of basic and main functions of human body (Heart rate and Body temperature). The proposed application triggers these measuring services every time is needed.
2. Level 2: Data communication (Sensor node): Intermediate controller unit which act as interface between sensors and reading aggregator from side and as Bluetooth wireless connection to the mobile for the other side
3. Level 3: Data acquisition: The sensors which are connected to the controller unit. These are heart rate sensor and temperature sensor
4. Level 4: Data Aggregation: The server on the internet used as the main repository
5. Level 5: Management: Mobile app used by the manager to monitor all data for the patients

A. Level-1: Application Platform.

Android based mobile application is used for monitoring and measuring the readings from the physical world into electrically defined signals in order to use these signals to map the readings to our core board. Our application read signals from sensors and filter them from noise and detect if the values are spikes or real measured values. Our proposed optimization algorithm will neglect the spikes and non-logical readings and the real logical readings are took into consideration to the processing phase. The processing phase consists of three algorithms for measuring Heart rate and Body temperature independently from patient's body, process those readings, and submit them into our proposed database which is connected to the patient profile. The specialized doctor can remotely examine and diagnose the patient's condition remotely and efficiently. Our processing unit samples analog values from the sensors through the Analog to Digital Converter module (ADC) and send through Bluetooth connection based on serial communication between processing unit and Bluetooth module

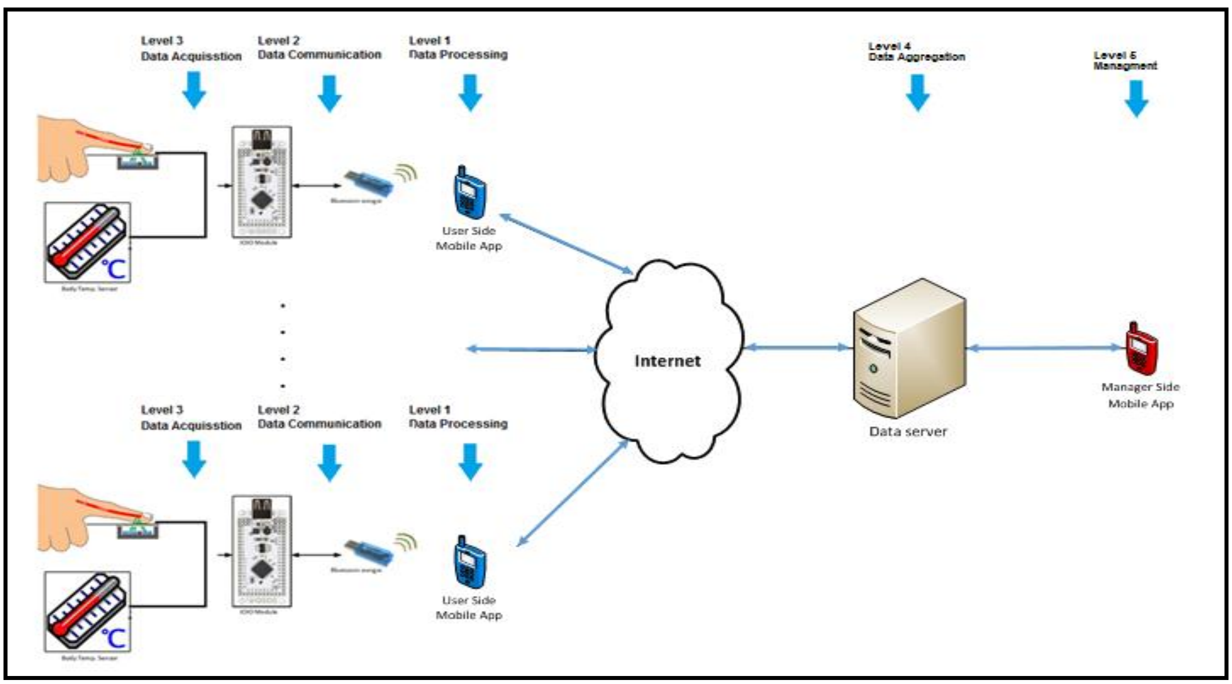


Fig. 1. Global system architecture with 5 levels

B. Level-2: Communication and Sensor nodes :

a. Central Control Unit (CCU) Interface.

There is hardware protocol layer, i.e. using Bluetooth device or USB connection. Above that, there will be framing for that protocol - over Bluetooth, it uses UART emulated connection. Over USB, it can use various Android defined protocols. Above that is the IOIO Application Protocol, which allows an application, running on the control device to access the pins and commands of the IOIO Board uses multiple protocols to communicate with control device. Sensors are interfaced with IOIO module, is considered the brain of the circuit. IOIO module monitor the measured values from the physical world from sensors and send them to the mobile application, in order to display the data to the user via Bluetooth [14].

b. Communication with sensors.

IOIO module and sensors are connected via a wired connection, IOIO module is communicating with the smartphone using USB micro cable or via Bluetooth connection.

C. Level-3 : Sensors (Data acquisition)

Sensors are devices that are used to measure physical variables like temperature, pH, velocity, rotational rate, flow rate, pressure and many others. Most sensors do not indicate a reading on an analog scale (like a thermometer, Microphone, Loud Speaker, and Biological Senses, but, rather, they produce a voltage or a digital signal that is indicative of the physical variable they measure. Those signals are often imported into computer programs, stored in files, plotted and analyzed on computers [15].

1. Heart Rate Sensor Node:

Optical Heart Rate Monitoring (OHRM) on intelligent platform like smart watch or smartphone provides the capability to continuously and unobtrusively monitor physiological metrics. The front of the sensor is the pretty side with the Heart logo. This is the side that makes contact with the skin. On the front, a small round hole, which the LED shines through from the back. The heart has a collection of pacemaker cells. A chemical reaction triggers these cells periodically (roughly once every second), resulting in a bio-potential wave propagating through the heart. This can be sensed using a pair of electrodes connected at two different points on the body. The periodicity of peaks is a direct measure of heart rate. A popular commercial device based on this concept takes the form of chest strap, which is inconvenient for prolonged heart rate monitoring. Sensing bio-potential from the heart is not the only mechanism of measuring the heart rate. The principle of OHRM is the light getting reflected from all components other than the arteries is time-invariant and contributes only to a DC level. Only light reflected from the arterial blood has a time variant (AC). A photodiode receives the reflected light and converts it to a current as shown in Fig 2. Parameters like spectral response, sensitivity, response time, and optimum separation between the LED and photodiode need to be considered while choosing the OHRM sensor. It is also important to reduce the effects of ambient light and to choose only the optical signals reflected from the body. This can be achieved by placing optical barriers or isolators between and around the LED and photodiode. Sensor modules with integrated LED and photodiodes solve many of optical design challenges [16].

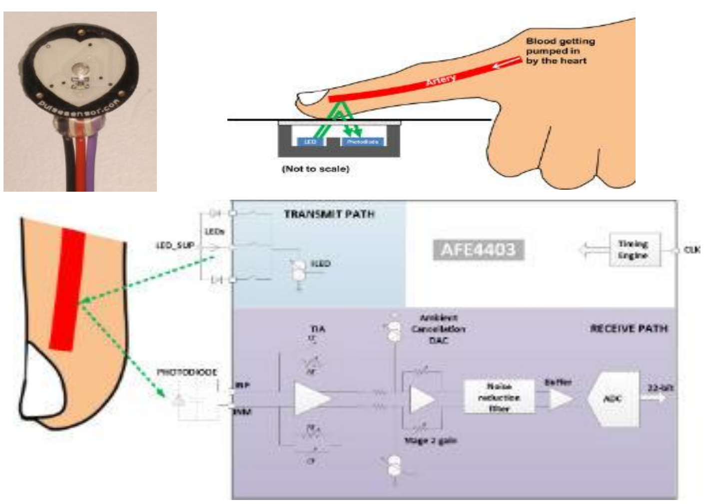


Fig. 2. Heart Rate Sensor Node

2. Body Temperature Sensor Node

Human body temperature sensor is used for measuring the temperature of patient. We used YSI 400 series thermistors, which thermistors provide highly accurate and stable temperature sensing for applications of temperature measurement, control, indication and compensation. Typical uses include precise measurements without the necessity of individual circuit calibration and with the advantage of precision interchangeability of sensors. Precise cold junction compensation of thermocouples may be designed directly without "bread boarding" after mathematically deriving the circuit because of the superior interchangeability of YSI precision thermistors. Fig 3 illustrate temperature sensor components [17].

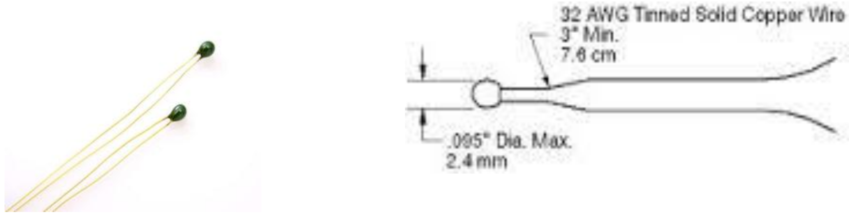


Fig. 3. Temperature sensor components illustration

- **Temperature Resistance Equation**

Unlike RTDs (Resistance Temperature Detectors), whose resistance is linearly proportional to absolute temperature, the resistance of thermistors changes dramatically and sensitively with temperature, satisfying an exponential relationship. To convert the measured resistance to temperature, you can use chart, or a portion of it, as a lookup table in your software and interpolate between adjacent degrees, or the equation you could use in an instrument to convert the measured resistance value to temperature in °C is ,

$$T = \frac{1}{(1/\beta)\ln(R/R_o) + 1/(T_o + 273.15)} - 273.15 \quad (1)$$

But sometimes, you may need even greater accuracy. A commonly used formula used to fit thermistors uses a fifth order polynomial in the logarithm of the resistance, as,

$$T = \frac{1}{a + b\ln(R/R_o) + c\left(\ln(R/R_o)\right)^3 + d\left(\ln(R/R_o)\right)^5} - 273.15 \quad (2)$$

The parameters, a, b, c, and d, are found by curve fitting the equation to the thermistor data over the temperature range of interest. Afterward, the above equation is used at run-time to compute temperature from the thermistor resistance [17].

D. **Level 4: Data Aggregation:**

It is the system server allocated on the internet it acts as patients' data repository and the back end administration. Fig 4 give a snapshot for the backend system

E. **Level 5: Management System :**

This is the mobile application for management level. It is customized to act as part for hospital management system – if our proposed system is deployed in a clinic center or hospital -as it will enable the hospital manager to monitor the status of all patients distributed by deportments or sections.

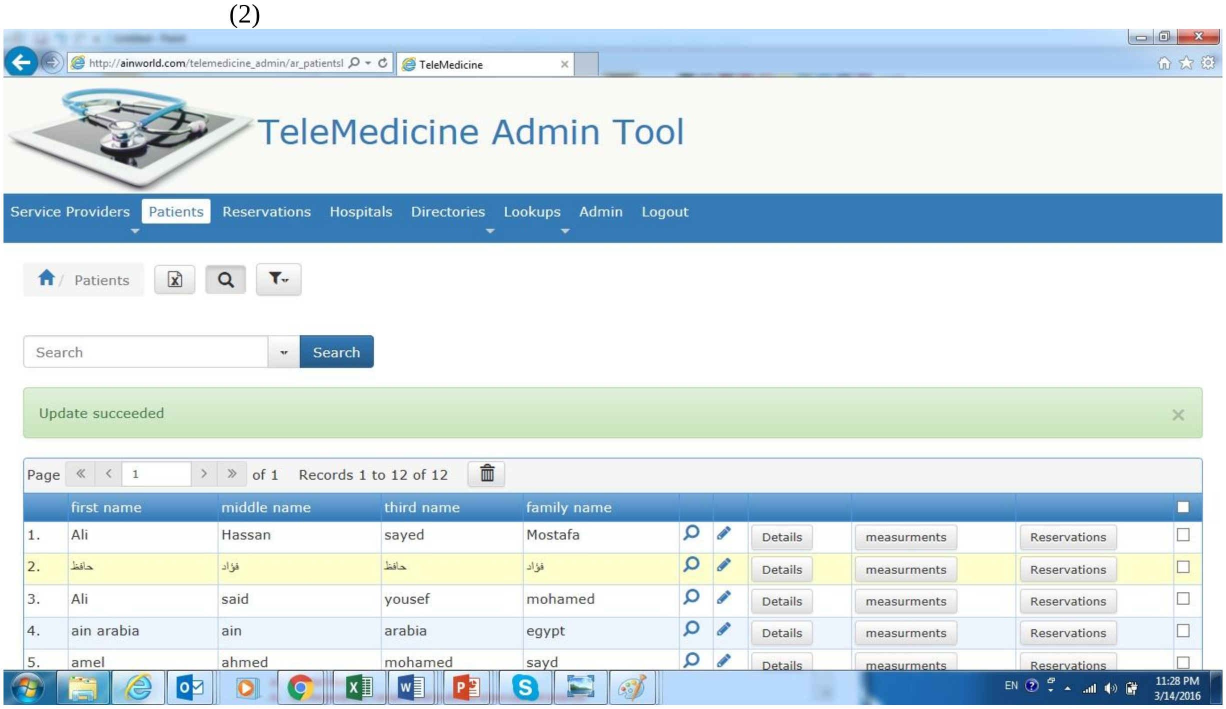


Fig. 4. Snap shot for the backend system

6. Proposed System Implementation

6.1. System Main Building blocks:

1. **Sensors:** are interfaced to microcontroller through analog module, the written software in microcontroller processes data and the processing results are sent to smartphone using Bluetooth.
2. **Analog module:** is used to get the electrical measured values from the real physical world and serve it to the brain (microprocessor) into an understandable format for the processing phase.
3. **Microcontroller:** Contains the microprocessor and the peripherals necessary for the operation.
4. **UART:** Is the communication module between the Bluetooth module and the microcontroller.
5. **Bluetooth module:** It is responsible for decoding and encoding data with Bluetooth standard.
6. **Smartphone:** to update the database and plot the response of sensors to the real word.

We replace the microcontroller and its interfaces with more reliable hardware component, android compatible module called "IOIO". Fig 5 gives detailed implemented components and system data

flow.

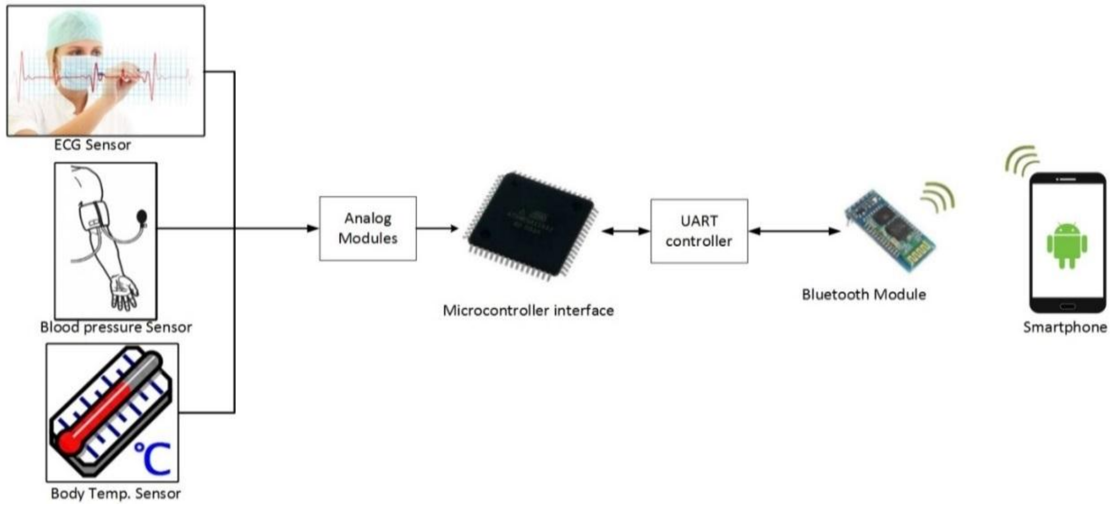


Fig. 5. Proposed System and components implementation

6.1. Sensor nodes Circuit Implementation:

It is data processing center. It is responsible for collecting data from different nodes through "Wi-Fi" network and process them to extract useful information.

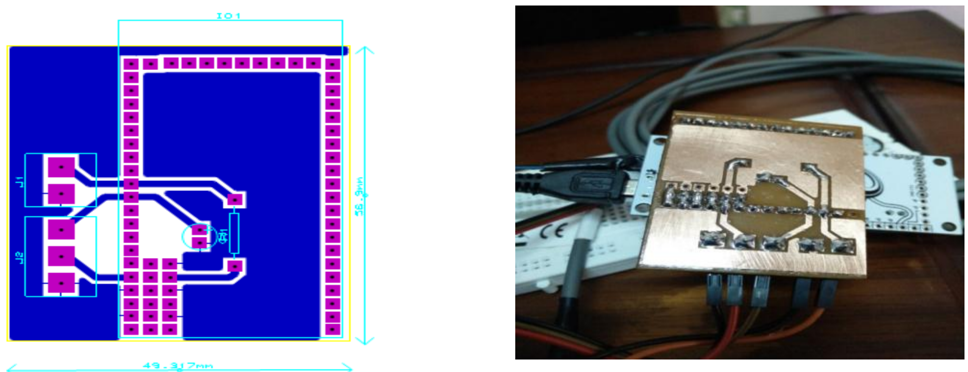


Fig. 6. Circuit (PCB schematic) for interface module and Sensor nodes Circuit Implementation.

It must always be active since the arrival of information is random. This is why his energy should be unlimited. In large sensor network where the charge is little higher, we can find two or more Sink to lighten the load. Fig 5 illustrate the board manufactured to act as interface board between sensors and IOIO board Fig. 6(a) the real layout of the board and Fig. 6(b) the true image photo. Fig 7 gives application GUI and detailed system components allocation. Fig 9 is a real photo for the real system with all components allocation description. Fig. 8 is a real photo for the embedded telemedicine system in "Cairo innovate" exhibition.

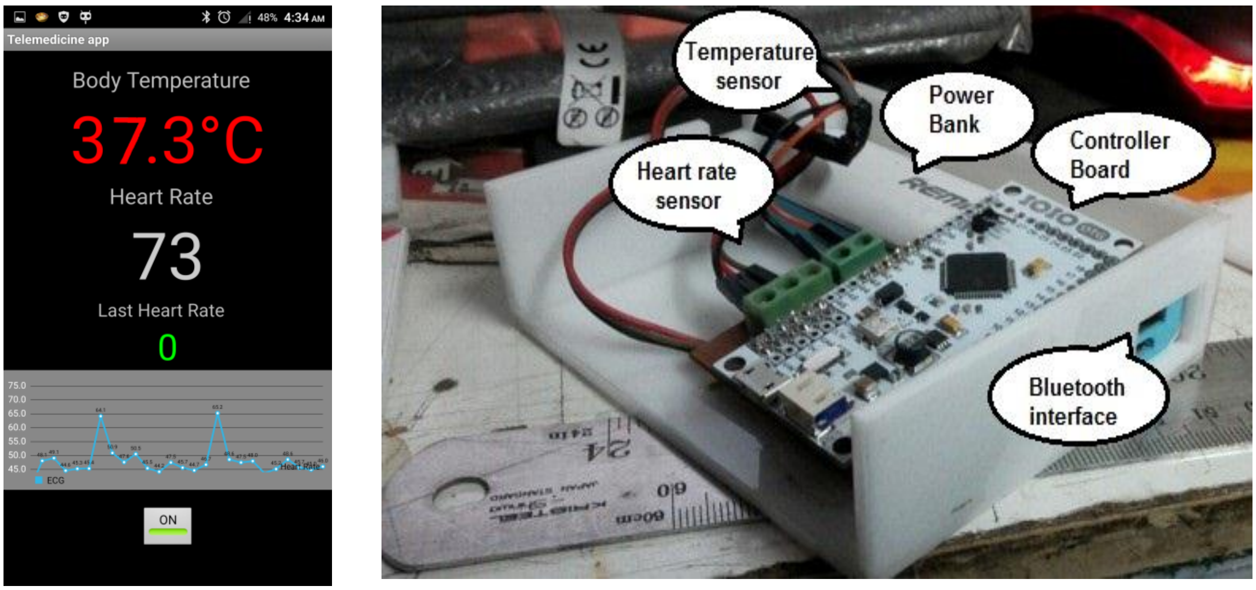
6.2. System characteristics

6.2.1. The proposed system power consumption:

- Bluetooth module: 50 mA.
- IOIO module: 50 mA.
- Pulse sensor: 10mA.
- Total: 110mA
- Power bank supply: 4000 mA
- Power efficacy assumption 70% of the power bank capacity
- Estimate working hours = (4000x0.7) /110 = 25 hours

6.2.2. System package Dimension

Length: 10 cm – width: 8 cm - Height: 3 cm



(a) (b)

Fig. 7. Mobile app. GUI and Detailed system components allocation and description

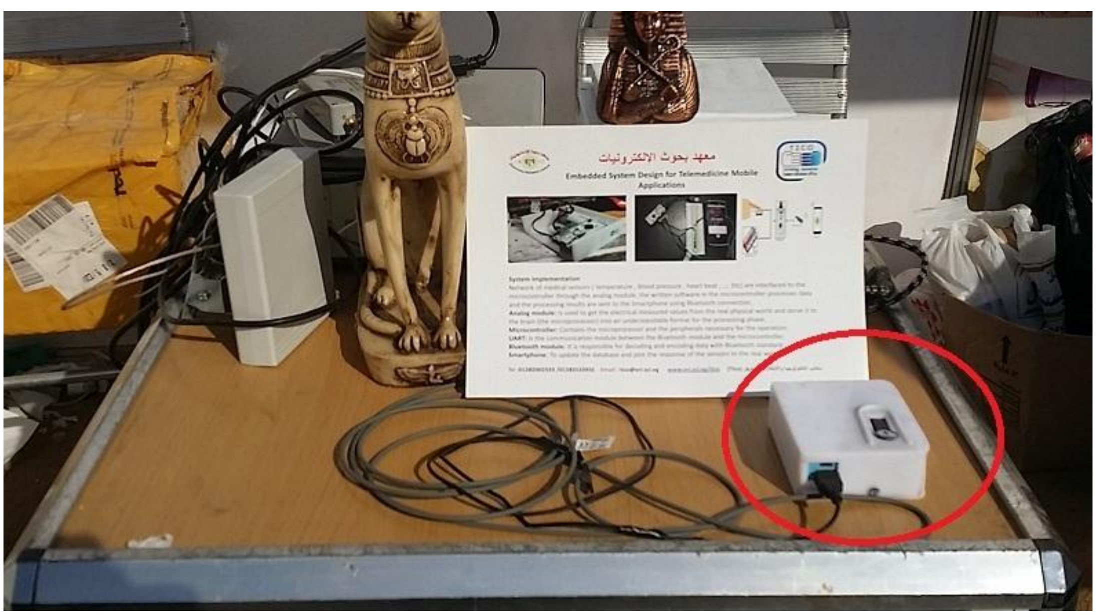


Fig. 8. Real image for the packed embedded telemedicine system

7. Discussion and considerations of the integration in the Internet-of-Things/Internet

Experimental evaluation of the proposed solution enables the readers to quantitatively evaluate the effectiveness of the system and the real contribution of the work.

The Novelty in this work emphasis new contributions in scientific relevance and Innovative work which is an integrated Architecture of embedded system for telemedicine mobile applications is proposed. The proposed system presents an efficient power operation with a power bank operation for more than 25 hours for the small power bank used in the proposed prototype could be enhanced to more than 50 hours for more efficient power banks with slight increase in the dimension. Moreover, an implementation of the proposed architecture is also reported. Develop an interactive Mobile GUI for healthcare providers. It also develops comfortable and portal medical wireless sensor network that provides continuous monitoring of health status for patients. Develop biomedical wireless sensor networks, compact, low-power, low SAR, plug-and-play for monitoring physiological activities, and environmental parameters using the latest available sensors. Design an easy use GUI to be used by doctors (or healthcare providers) in the diagnosis of their patients. Enable sharing medical multimedia data among distant sites (hospitals), using file transfer protocol (FTP). The proposed system also present an access to a databases to back up the telemedicine systems activities, and store all the information necessary in the web based telemedicine applications. The developed integrated system is efficient with respect to portably since it is one node of sensors, cost effective regarding the electronics components used, low power consumption which cover more than 25 hours with small power bank, and finally with efficient UI through a simple android mobile application.

8. Conclusion

An embedded microcontroller systems board, IOIO, and medical sensors node was designed and implemented. A mobile telemedicine application was developed based on conducting with the implemented medical unit. The controller board is connected wirelessly to the mobile application which act as data aggregator and sensors node interface. We apply our system on heart rate sensor and temperature sensor. The mobile application is android based and it is ready to be used on the individual level or on central level as hospitals and clinics. The mobile application also produces as bi-product; ECG graph resulted from the heart rate measure. An interface ADC module is developed and tested. Sensor nodes circuit is implemented to act as interface board between sensors and ADC. The developed integrated system is efficient with respect to portability, cost, power consumption, usability. The real layout of the board and the true image photo of the detailed system components allocation and description is given. The Proposed System Implementation contains Main Building blocks: First, Sensors, Second, Analog module: Third: UART: Fourth: Smartphone: to update the database and plot the response of sensors to the real word. Sensor nodes The Novelty in this work emphasis new contributions in scientific relevance and Innovative work since an integrated Architecture of embedded system for telemedicine mobile applications is proposed. The proposed system presents an efficient power operation with a power bank operation for more than 25 hours for the small power bank used in the proposed prototype could be enhanced to more than 50 hours for more efficient power banks with slight increase in the dimension. Moreover, an implementation of the proposed architecture is also reported. Develop an interactive Mobile GUI for healthcare providers. It also develops comfortable and portal medical wireless sensor network that provides continuous monitoring of health status for patients. Develop biomedical wireless sensor networks, compact, low-power, low SAR, plug-and-play for monitoring physiological activities, and environmental parameters using the latest available sensors. Design an easy use GUI to be used by doctors (or healthcare providers) in the diagnosis of their patients. Enable sharing medical multimedia data among distant sites (hospitals), using file transfer protocol (FTP). The proposed system also present an access to a databases to back up the telemedicine systems activities, and store all the information necessary in the web based telemedicine applications..

5. Future work

This system has many directions as future work tracks as:

1. Implementing an averaging technique with the measured values from the sensors.
2. Implementing an algorithm for noise cancellation.
3. Adding more sensors to the sensors node forming a wireless sensor network as blood pressure.
4. Working on the power consumption to be low for longer time power bank operated and for wearable objectives.

Acknowledgements

This work is supported by Electronics Research Institute, ERI, Cairo, and funded by Information Technology Industry Development Agency, ITIDA-MCIT, Cairo, EGYPT.

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