Design and Implementation of Low Cost, Portable Telemedicine System: An Embedded Technology and ICT Approach

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***Abstract*— In India, Primary Health Centre (PHC) were established to provide accessible, affordable and available first line health services. There are 23,109 PHCs in India and Under the National Rural Health Mission (NHRM) the Government is upgrading all the PHCs. Due to shortage of human resources, PHC system largely depends on "referral system", which in turn relies heavily on communication and transportation infrastructure. Communication and transportation put an upper limit on health care delivery to patient and some time it may cause casualties in remote areas. Development of Low cost Biomedical Sensors, Low cost Portable Embedded System, Internet and Smart phone based Telemedicine System may offer the opportunity to alleviate the health care system efficiency by number of application viz. data collection, chronic patient surveillance, to control the therapeutic procedure etc. This paper presents the work of design and implementation of low cost telemedicine system, which integrates the sensing, storage and broadcasting of various biomedical parameters of patient using low cost low weight and accurate biomedical sensors, BeagleBone Black as a computing unit and various softwares viz. Linux, Apace Server, MySQL and PHP. Implemented system is compared with various existing available biomedical sensors.**

Keywords*— *Embedded System, BeagleBone Black, Biomedical Sensors, Telemedicine, Remote Access, Information and Communication Technology

I. INTRODUCTION

The life expectancy and the consequent progressive aging of the life has been rise significantly over the few years in recent past, with a prevalence of chronic diseases, which in turn has triggered to think carefully on the role of providing utmost care to common man to increase life expectancy, much without changing the current infrastructure and environment. Hence, it becomes very important to think about the tools that may help us to plan our strategy to monitor the patient and therapeutic procedure, particularly in remote areas where qualified doctors are not easily available, with the help of advancement in electronics technology [1]. The paradigm of embedded system technology, in electronics domain can help us to design and implement a low cost biomedical sensors and storage as well ease access to central patient clinical database on low cost, but yet powerful enough single board computer (SBC).

Over the development of various technology emerged, the combination of embedded system and information and communication technology (ICT) can help us to replace costly and bulkier current telemedicine system with low cost, low weight and easily portable telemedicine system, which is the demand of current scenario in rural India. Telemedicine has significant impact on the monitoring of patients located in remote nonclinical environments such as rural homes, military bases, ships, and other distant areas. A number of applications, ranging from data collection, to chronic patient surveillance, and even to the control of therapeutic procedures, are being implemented in many parts of the world [2], [3]. A telemedicine system composed of SBC, some important and accurate low cost biomedical sensors and their accurate interface with SBC, the user friendly software environment and a provision of feedback provided by doctors is demand of present days in developing countries like India [2].

The paper presents a design and Implementation of low cost ICT based real-time remote patient monitoring service through World Wide Web (WWW), which allows physicians to monitor their patient in remote sites using Web browser. The system is composed of data acquisition and preprocessing module contained in an onboard computer equipped with network and analog to digital cards, software modules to create physician specific patient oriented databases and handle communication protocols between data acquisition module and onboard computer. The purpose of the system is the provision of extended monitoring for patients through their body temperature, blood pressure, glucose level measurement and, in some particular cases, remote consultation, and low-cost ECG monitoring.

The remaining part of the paper is organized as follows: the section II presents the existing scenario and system proposed in this paper. The hardware environment is presented in Section III. The software environment is outlined in Section IV. Section V show the results and finally we conclude the paper with future scope.

II. EXISITING SYSTEMS

The good hospitals and qualified doctors are not easily available in developing countries particularly in undeveloped villages and remote regions. In some medical condition the

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round the clock monitoring of patient is required. Also in some cases, e.g. very old people and small children, their relatives are reluctant to keep the patient in hospitals. Also, in so many government hospitals, enough number of beds are not available. Sometimes the patient has to travel a long distance to avail the needed medical treatment.

The telemedicine has been the one of the hottest topic for researcher in recent decades. Many people have worked and presented their ideas and many patent has been [3], [4], [5]. In [7], judy et has presented work on monitoring the patient remotely through custom fitted medical devices and a mechanism to send the alarm to the remote monitor by device. However, the system lacks of low cost solution as it would be difficult to manufacture and install customised equipments. Dicks et in [8] has presented a scheme to monitor patient data through medical sensors and transmit the senses information later to a processor. However, the problem to such approach is to configure the each sensor separately to the processor, which in turn is not good user interface for non-technical persons or nursing staff in remote areas.

In paper [9], [10], [11], [12], [13], the problem to the remote monitoring has been addressed by mobile phone, closed circuit television (CCTV) and rotating webcams. However, the data rate available in remote areas, particularly in undeveloped regions, puts an upper hand on overall performance of the system and do not possess the feature of reverse path, i.e. doctor to patient. In [14], the authors have presented a telemedicine system, which uses satellite technology. However, it could be very difficult issue to get low cost Avaiblity of satellite transponder channel and may consume more power, which may lead to another issue of continuous avaibility of 3-phase power in rural and remote areas.

The existing solutions are suffering from the drawback such as bulky in size, requirement of more space, higher cost due to customized solution, higher maintenance and running cost due to uneasy user interface and requires a special technicians to monitor. The main drawback of the systems is, no avaibility of easy interaction link from doctor side to patient side, once the clinical data has been got. The system presented in the paper provides a low power, low cost, easy to operate, simple, secure and effective reverse communication link from doctor side to patient side through access of patient's clinical database through www via either desktop-laptop or smartphone.

III. Hardware Environment

The figure 1 shows the block diagram of system designed and implemented. In the Hardware area, we have selected the proper onboard single board computer, in form of BeagleBone Black (BBB), configure it with Ubuntu Operating System (OS) through the Secure Digital (SD) memory card and connect it to the Internet. We have selected the proper sensors: like Blood Pressure sensor which provides vital information of the human body's blood pressure, the ECG sensor which gives yet another important parameter: Pulse value. The temperature sensor is helpful in determining the body temperature values The final step was to properly calibrate and interface these sensors with the BBB.

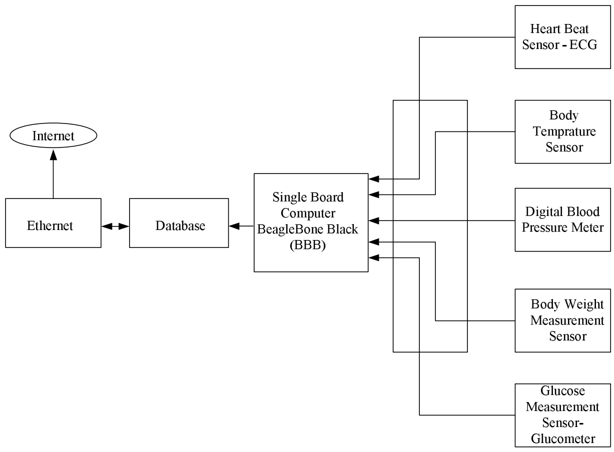

Fig. 1. The block diagram with the bio-medical sensors interfaced with the Beagle Bone Black which is further connected to the Internet through the Ethernet.

The carefully designed hardware is backed by quality Software work, we have built a running dynamic website using the Linux, Apache 2.0, MySQL and Hypertext preprocessor-PHP (LAMP) server that would help doctors in remote location to access to their patients clinical data and provide prescription. We were able to emulate Ubuntu terminal on our Personal Computer (PC) through the use of Moba X-Term software. We accomplished the interfacing of MySQL with C thus allowing our code to be more dynamic. Through this C code, we were able to configure the Universal Asynchronous Receive Transmit (UART) and Analog-to-Digital converter (ADC) ports of the Black to receive data from the sensors.

A. BeagleBone Black (BBB)

The first step in development of system is, selection of the necessary board as onboard computer. This computer should have network support and ability to be interfaced with the sensors. The sensors are also an integral part of the system. To gather the information from the analog sensors, in the digital form, there is a need of onboard ADC with OS support, provided that, the ultimately developed system will be more compact and reliable.

Panda board can be selected to suffice the need of the onboard computer. It possesses Bluetooth and Wi-Fi support, as demanded by the system. Though it lacks onboard ADC. Apart from that, its cost also comes into picture. That makes BeagleBone Black (BBB) a perfect choice for the desired application, which has far less cost than any other board with onboard ADC support. BeagleBone Black is a community supported platform board manufactured by a number of companies. It's manufactured and designed by beagleoard.org, a manufacturer of several successful onboard computers [17].

Table 1 shows the comparison of various SBCs, and which clearly confirms that BBB is the best choice for the requirement. Further BBB is very light weighted compare to desktop computers typically used in telemedicine system, hence it make us to transport entire system to build around 3 Kg. So the entire module can be transported very easily.

TABLE 1. COMPARISON OF DIFFERENT SBC [15] [16] [17]

Panda Board ES	BeagleBone	BeagleBone Black
OMAP4460 ARM cortex A9 processor	TI Sitara ARM cortex A8	TI AM3359 ARM cortex A8
1.2 GHz max processing speed	720 MHz	1 GHz max processing speed
Dual Core	Single Core	Single Core
1 GB RAM	256 MB RAM	512 MB RAM
No Flash Memory	No Flash Memory	2 GB onboard Flash Memory
2 Host, 1 OTG	1 Host, 1 OTG	1 Host, 1 OTG
Ethernet 10/100M	Ethernet 10/100M	Ethernet 10/100M
1 HDMI, 1 DVI-D	1 DVI-D	1 Micro HDMI
1 uSD cage, 1 through expansion	1uSD cage	1 uSD cage
182 $ price	89 $	45 $
--	SGX 530 GPU	SGX 530 GPU
Analog video I/O	No Analog video I/O	No Analog video I/O
Wi-Fi	No Wi-Fi	No Wi-Fi
Bluetooth	No Bluetooth	No Bluetooth
No onboard ADC	No onboard ADC	Onboard ADC

The choice of BBB as single board computer satisfy our requirement to develop Light weighted, Low cost embedded system based telemedicine system.

B. Bio-medical Sensors

The good telemedicine system requires the accurate sensors. The sensors developed for the system are low cost and accurate.

1) Heart-beat Sensor: Blood pressure is the pressure of the blood in the arteries as it is pumped around the body by the heart. The Blood pressure sensor, that also counts the pulse rate, was interfaced with UART 1 RXD pin (P9_26) of BBB board.

The specification for the sensors are as under:

- Working Voltage: +5V, 200mA regulated.
- Output Format: Serial Data at 9600 baud rate (8 bits data, No parity and 1 stop bits). Outputs three parameters in ASCII.
- Sensing unit wire length is 2 meters. The Sensor used is available from [18].

2) Temperature Sensor: NTC Thermistor which measures the body temperature, is interfaced to AIN1 (ADC) pin (P9_40) of the board. The body temperature sensor or ambient temperature sensor is interfaced through the ADC pins to the board. The analog voltage from the sensor is read by the analog pin of the board provided the voltage is between 0 to 3.3 V. The on board ADC converts this analog value in the digital form and average value is calculated. From this average value we can calculate the temperature of the body using SteinHart-equation [19].

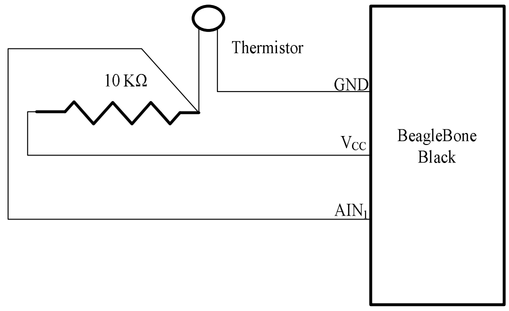

Fig. 2. Temperature sensor interfacing with BBB.

$$ADC\ value = R / (R + 10K) * 1023 \qquad (1)[19]$$

3) SPO2 Sensor: Sensor measures the Oxygen content in the body. Oxygen content in normal human being is above 95%. The sensor clip uses Red /IR Led pair coupled with PIN photodiode. Depending on the amount of oxygen in blood, proportion of Red and IR light is absorbed. More is the Oxygen more is the absorption of IR light. This absorption is detected by PIN PhotoDiode. These detected signals are passed through BandPass Filters and given to the ADC of Beaglebone Black. Proper calculations are done in measured ADC values and SPO2 percentage is calculated.

Following Circuit were Implemented:

a) LED Driver Circuit: Figure 3 shows the interfacing of sensor circuit with BBB. Sensor consist of IR LED and RED LED with some transistors to increase current.

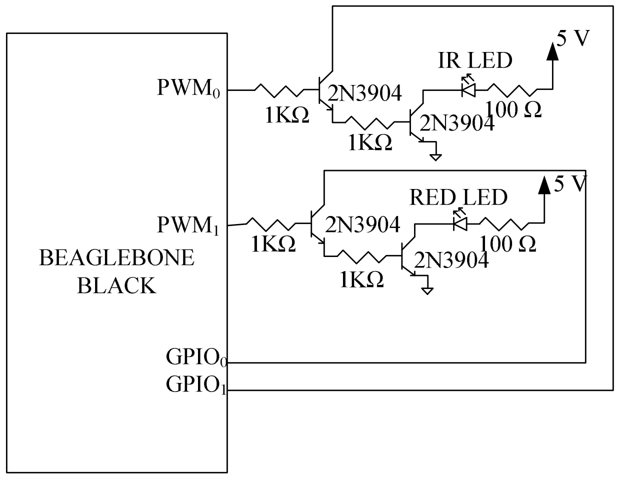

Fig. 3. LED Driver Circuit for SPO2 Sensor [20]

Here the RED and IR LED are turned on and off alternatively for 25 ms by BBB using Pulse Width Modulation (PWM) and ADC readings are calculated. This circuit requires lot of calibration on hardware as well as Software side

b) Detector Circuit:

The detector circuit is designed using op-amp IC LM358, which is configured as inverting amplifier and its output is given to on chip ADC for SPO2 measurement.

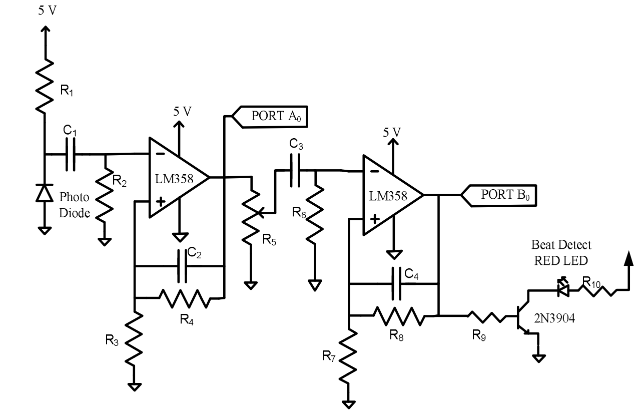

Fig. 4. Detector Circuit [20]

4) Weight Sensor:

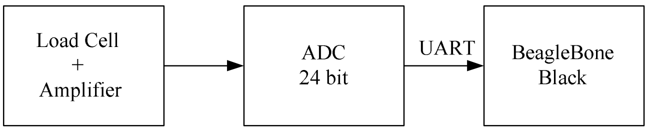

Fig 5. Weight Sensor Block diagram [18]

The weight sensor, shown in Figure 5, consist of Load cell as sensing unit which is connected to on board ADC of Beagle Bone Black via Amplifier and a program is written to sense the ADC output and finally it is stored in database. The proper mechanical platform is required to be made. Sensor gives serial output. Its RX pin is connected to P9_24 and its TX pin is connected to P9_26 of BBB

TABLE I. TABLE II. SPECIFICATION OF WEIGHT SENSOR

Name	Value
Working Voltage	5 V DC Reg
Output Reading Rate Every	100 ms
Data Format	12 byte ASCII
UART baud rate (8 bit data, no parity, 1 stop bit)	9600 bps

5) Glucometer: The output of the sensor is interfaced to one of the ADC pin of BBB. The following equation 2 can calculate the output.

$$Y = M*(ADC) + C \quad (2)$$

The value of M is the regression equation of this glucometer. The relation between glucose concentration and ADC value can be calculated by testing the known solution of glucose concentration and noting down the ADC values. The value C, being calibration error. Calibration error is calculated carefully y various experiments and applied in programming for correction.

6) Electro cardio Gram (ECG) Sensor: The IC AD8232 based module is a cost-effective board used to measure the electrical activity of the heart. This electrical activity can be charted as an Electrocardiogram and output as an analog reading. ECGs can be extremely noisy, the AD8232 Single Lead Heart Rate Monitor acts as an op amp to help obtain a clear signal from the PR and QT Intervals found in ECG signal easily. The AD8232 is an integrated signal conditioning block for ECG and other bio potential measurement applications [21]. It is designed to extract, amplify, and filter small bio potential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement.

IV. SOFTWARE ENVIRONMENT

The proper hardware designed should be backed up by well written software. The Software environment is configured on Ubuntu OS. The Dynamic database is created in MYSQL. The Apache is webserver application and the webpages are created in PHP.

We used Ubuntu 12.04.03 OS for the BeagleBone Black (Precise Pangolin). As it is open source, easy to use and provides with a large number of applications to use, it became an obvious choice for us to use it on the board. It is one of the most popular desktop linux distribution.

Database is created in MySQL using phpMyAdmin. The name of the database we have used is “telemedicine”. It consist of many sub tables that stores information about Patient information, Doctor Information, Admin Information. This information is stored by a dynamic “Python Code” that is running on the patient side and that takes information from the sensors. Once the information is stored it is uploaded on internet using LAMP package. Doctor from any remote place can see the database of the patient. Doctor can write prescription from any remote place which is stored back into the database. Hence Database is dynamically updated and plays the role of the core of entire LAMP package and software system.

Apache 2.0 – Apache server is a web server application, provides a full range of Web server features including CGI, SSL, and virtual domains.

PHP is a server side scripting language used along with MySQL to create dynamic websites. PHP codes or scripts are used to access as well as edit the database of MySQL from anywhere in the world through building a website. PHP codes can be written inside a simple text editor like Notepad. They can be embedded inside the Hyper Text Markup Language (HTML) codes itself. PHP has much strength like high performance, interface to many database management systems, built-in libraries for many Web tasks, low cost, portability and availability of source code. GIF-images on the fly, Portable Documents Format (PDF) documents, email, connecting to other network services can be easily done using PHP. PHP is very efficient. Using a single server, it can be used to serve millions of hits per day. The Webpages are developed in PHP and they have been linked up with database and onboard server

MySQL (Standard Query Language) – is an open source relational database management system and used along with PHP in a wide range of applications including dynamic website creation. It stores data in tabular form and values can be easily added and deleted from this database. MySQL is available for various UNIX systems as well as MS Windows. Most modern databases use SQL. It is a multi-user, multi-threaded server. As the same goes with PHP, the source code is available and can be modified for MySQL.

As per the requirement, the web-pages are developed using PHP. Those will be broadcasted by the server once its name is written in the URL bar following the IP address.

V. RESULTS

The flow of process for the developed system is depicted in the form of webpages from figure 6 to figure 12. The webpages can be accessed by registered doctors and administrator anywhere in the world through personal computer or smart phone having internet access by typing unique web address in browser window.

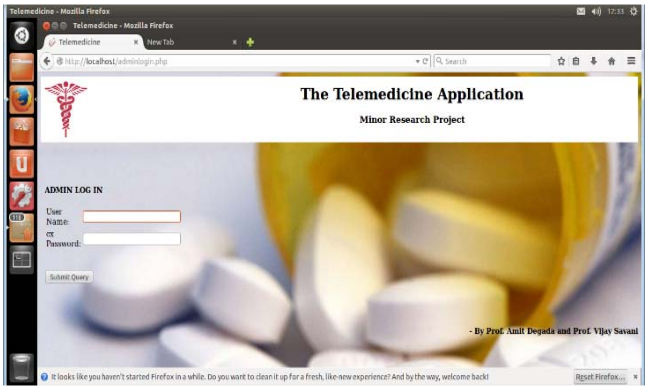

Fig. 6. Login Page for Administrator.

Figure 6 shows the login page for the administrator. Similar webpage is created for login to the doctor. Administrator can create the new entries for the doctor, patient and assign patient to the doctor.

Administrator can see the information of registered doctor and clinical database of patient as well as prescription provided by doctor, so later on the prescription can be passed to patient for diagnosis. This is shown in Figure 7.

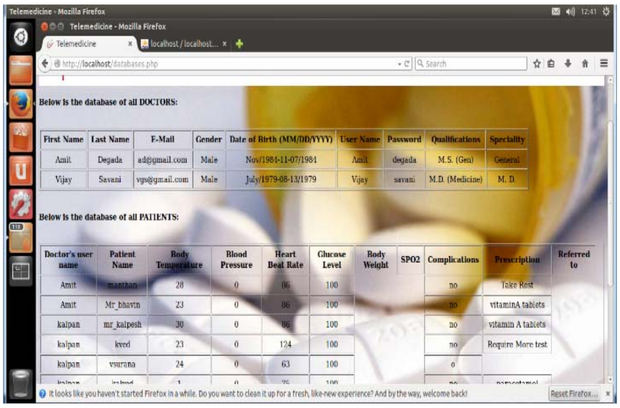

Fig. 7. Administrator Window.

Figure 8 depicts, the webpage that shows how a new doctor can register in to the system. The doctor's registration is authenticated and approved by administrator.

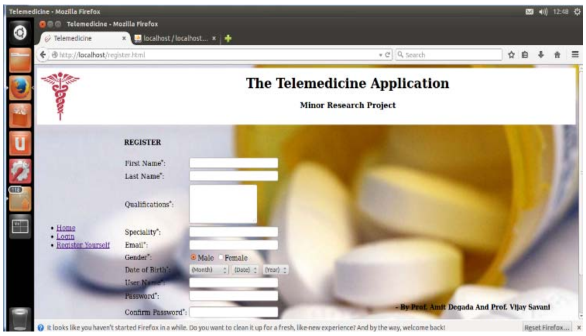

Fig. 8. Webpage to register new doctor.

Similarly a new patient can be added to system by administrator as shown in Figure 9.

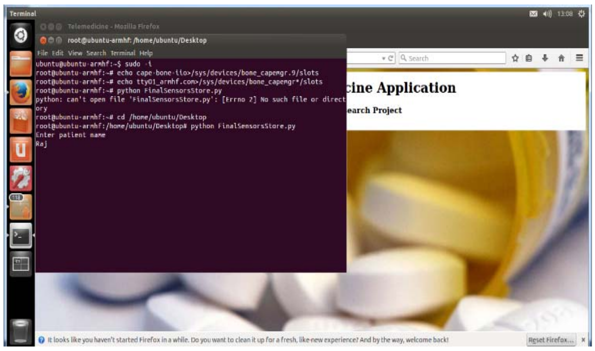

Fig. 9. Registering a new patient.

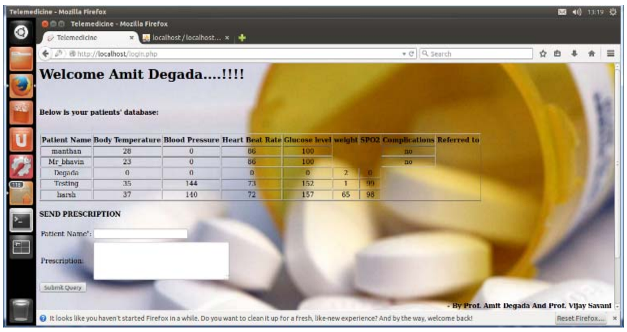

Fig. 10. Data base of patient's clinical information as seen by doctor.

Figure 10 shows the number of patient assigned to particular doctor, once he/she login to the system. The doctor can read the clinical data of the patient and according to the condition he/she may prescribe the diagnosis to particular patient.

The system can also make available the history of medical diagnosis given to a patient, if doctor wish to check. Hence, the system satisfy the path to communicate from doctor side to patient side. One of the objective of telemedicine system is to provide the referral to another doctor. This feature is available also made available system developed.

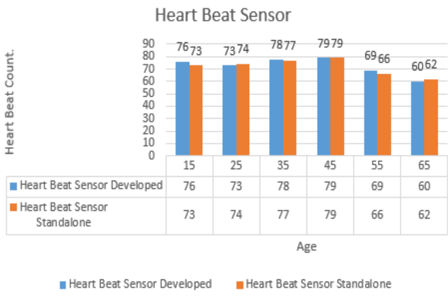

Fig. 11. Heart Beat Sensor data for sensor developed vs. actual sensor

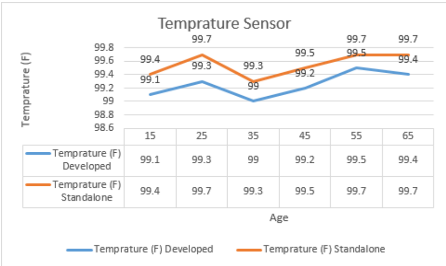

Fig. 12. Temperature Sensor data for sensor developed vs. actual sensor

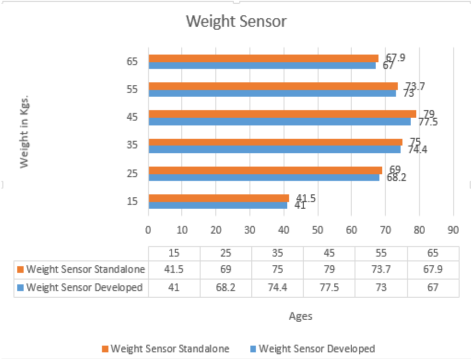

Fig. 13. Weight Sensor data for sensor developed vs. actual sensor

The graph shown in Figure 11 to 13 is the comparison of various sensors developed in this schemes are compared for standard standalone medical sensors available in clinics. The data is obtained for sample patient basket consist of good healthy people, from age 15, 25, 35, 45, 55 and 65 years. The biomedical parameters are hardly affected by age and current healthy situation. The average value of five experiments done for each age patient has been considered. It is verified from the figure that most of the sensor developed here works perfectly and the variation in the output of sensor is found very less.

VI. Conclusion & Future Scope

One of the basic ideas of telemedicine can be expressed by the saying: "Move the information, not the patient". The system develop here, satisfy above objective for basic clinical data observation with low cost and that to with good efficiency. Potentially allows easier access to more information about a patient at remote location. The various sensors viz. heartbeat, temperature, weight, blood pressure, ECG and Glucometer are developed and interfaced successfully with BBB. The system permits to build computer-based patient records and other electronic information systems that provide relatively easy and fast access to large databases and that yields easily diagnostic link from doctor to patient. The system developed here is very light weighted, so it is very easy to transport from one place to another. The future scope is to add more features to the system, such as CCTV link, and to add more sensors such as Capnographic sensor to measure CO_2, and electroencephalogram (EEG) data. Further the ECG, Heart Beat and Gluco-meter sensor's output can be compared with standard output.

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