Design of Internet of Things (IoT) & Android based Low Cost Health Monitoring Embedded System Wearable Sensor for Measuring SpO2, Heart Rate and Body Temperature Simultaneously.

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***Abstract*- In this paper, an implementation of affordable medical technology health monitoring sensor system is developed and demonstrated to measure blood saturation levels (SpO2), heart rate and body temperature simultaneously. The embedded system is based on Arduino platform due to reliability and plug and play capability. The proposed pulse oximetry sensor uses spectrophotometry to calculate the ratio of oxygenated hemoglobin to deoxygenated hemoglobin which then is used to calculate the percentage of oxygenated blood levels. The accuracy of pulse oximeter is enhanced using Light Emitting Diodes (LED) driver circuits, Sample and Hold (S/H) circuits thus that a variable baseline can be established for different skin tones including the finger width where the measurements are undertaken. The embedded sensor system is designed to monitor SpO2, heart rate and body temperature and display the obtained results on an LCD. The measured vitals are also transmitted via Bluetooth module to Android mobile, and using Wi-Fi module to the internet, forming Internet of things (IoT) platform for the designed embedded system of sensors. The low cost embedded sensor system reported in this study can be used to monitor key health parameters of patients in hospitals or at home. The proposed affordable medical technology sensor system can be used as wearable wireless sensor which can be used as a plug and play sensor with Arduino to monitor human key health**

parameters. The measured health parameters are compared with commercially available ChoiceMMed Pulse Oximeter and a maximum deviation of 2% is observed which demonstrates that the proposed sensor device is highly accurate.

***Keywords*- Wireless Sensor, Pulse Oximeter, Heart, Spectrophotometry, Internet of Things (IoT).**

I. INTRODUCTION

With the advancement in the field of medicine elderly population grows in all countries including developed countries due to vaccination, better health care facilities and medicines [1]. However, that increases the demand of healthcare facilities and medical staff. Growth in electronics industry resulted in various health care devices and sensors that are supporting human life i.e. peacemakers, medical glucose monitor, medical heart rate monitors, Sphygmomanometer and electronic stethoscope. IEEE is working on improving and developing new standards to transmit and collect human health data i.e. IEEE 11073 [2, 3]. Simultaneous monitoring of pulse rate and blood oxygen saturation levels help managing shortness of breath due to pneumonia or heart attacks for example through combination of drugs and proper breathing techniques to increase their blood oxygen saturation levels from low saturation to all the way up to 93% [4]. The home health care mobile applications using on board health monitoring sensors is expected to grow to 95% by 2020 but typical mobile devices price from 399$ to 550$ puts it out of reach many developing countries [5]. Home Health care monitors have the potential to enhance patient access issues. About 20% of US population live in rural areas and 9% of physicians work in rural areas [6]. As a result, embedded system may allow patients to monitor their health at home or medical facilities without the need of medical personnel with overall reduction in healthcare cost. Home healthcare is fast growing industry which offers several advantages to patients, as well as to the population. Technology that allows patients to be medically monitored from home reduces the burden of travelling to physicians' offices and waiting for physician availability [6]. Such technology therefore provides flexibility in health management. Medical monitoring also has several specific health benefits. For example, its use improves diagnostics and treatments and lowers costs associated with medical care. Previously published non-invasive wearable ring sensors for real-time monitoring of blood pressure, SpO_2 and glucose levels in blood represent a step toward realization of personal health monitoring of patients and non-patients using ICT based technology that would have significant effects improving people's life in terms of personal health self-awareness and reducing the health system associated costs [7, 8, 9]. The financial advantages of medical monitoring are likely to grow as the relevant capabilities of mobile technology flourish. Hence, in this paper, we are focused on developing a low cost, easy to use, portable and reliable health monitor system which can measure SpO_2 levels, pulse rate and temperature.

The oxygen saturation level within the blood is very important, known as one of the 'vitals', it is one of the standard measurements for health professionals. SpO_2 is defined as the percentage of haemoglobin with bound oxygen and is termed as SpO_2 when measured by a pulse oximeter. The average level is 95-100% [10]. Pulse Oximeters are medical sensors used to determine percentage of oxygen saturation levels in blood non-invasively [7]. Pulse Oximeter is an important device which is used during Medical Intensive Care Unit (MICU), Labour, recovery and operations to determine patient oxygen concentration non-invasively.

A proposed real-time health monitoring system to measure human bio-signals using different sensors known as CaszOxiSys which uses a combination of photodiodes and LEDS to measure blood saturation levels & heart rate using the information extracted from the bio-signals which are then conveyed to personal computer using Bluetooth module. Currently a great deal of health monitoring sensors is available in the market. Samsung has presented S health in cell phones which can compute Blood saturation levels and heart rate [11] but this paper focuses on developing a health monitoring system which has low cost and accurate pulse oximeter sensor, Heart rate sensor and temperature sensors designed and incorporated with Arduino board to measure blood saturation levels, pulse rate and temperature respectively, at the same time the data can be transmitted to internet or mobile phone at low cost so it can be used by elderly at home, clinics and third world countries.

The working guideline is oxygenated haemoglobin (HbO_2) and deoxygenated haemoglobin (Hb) retain different quantities of light wavelengths, so two different wavelengths generally Red (640nm) and Infrared (950nm) is shinned on blood and their proportions absorbed by blood help decide SpO_2. Pulse oximeter is an imperative non-invasive technique used to screen individual oxygen absorption. SpO_2 sensors are imperative particularly when individual oxygen absorption in blood is unsteady. The sensor uses Red and Infrared LEDs with phototransistor to convert the light received after modulating by human tissue to electrical output. The output consists of large DC component and small AC signal of 10-30mV magnitude. The DC part is due to tissues, Bone and non-pulsatile arterial blood while the AC part is due to pulsatile volume of arterial blood. This output is filtered, amplified and given to Analog to Digital Converter of microcontroller to calculate Blood oxygen saturation Level [11].

The blood oxygen saturated levels are calculated using a well know Mendelson and Kent equation which is derived using Beer-lambert law [11-12]. Pulse oximeter sensor is made up of two LEDs of different wavelength red (640nm) and Infrared (900nm) which are turned on and off alternatively. The light is shinned on thin body part i.e. finger, ear lobes etc. Each wavelength is modulated by blood depending upon the quantity of oxygenated haemoglobin and deoxygenated haemoglobin. The absorbance of light in the red region of the spectrum is much higher for reduced haemoglobin than for oxygenated haemoglobin. The reduced haemoglobin is more transparent to light from the infrared region than oxygenated haemoglobin.

A combination of high pass and low pass filters to block DC component in blood as well as unwanted high and low frequencies caused by power supplies and non-ideal properties of Op-Amp is already employed and found effective while obtaining blood saturation levels [13]. The same technique is used to block unwanted parts of phototransistor output. The same output is passed through another circuit to create rail to rail shifts from 0 Volts to 5 Volts with the heart contractions and expansions respectively. The microcontroller measures the time it takes from rail to rail shifts (0V to 5V) and calculate the average to provide more reliable reading [13].

The AC maximum, AC minimum and DC components of these two wavelengths after passing through human body is determined to calculate the SpO_2 level by using the Mendelson and Kent equation which complexity can be reduced to following mathematical formula. DC level of light represents the intensity of light which is being shinned as the intensity increases so does the AC wave, that is why it is necessary to get a result in term of each wavelength ratio of AC signal which represent the Absorption Ratio to DC component representing the intensity of LED of particular wavelength. The following equation (1) is used to find ratio which is used to determine the blood oxygen saturation levels [14].

$$R = \frac{(AC/DC)_{RED}}{(AC/DC)_{IR}} \quad (1)$$

The ratio of Red wavelength being absorbed by the blood to Infrared wavelength absorbed by the blood is calculated by using AC components of the RED wavelength meaning the small signal as a result of contraction and expansion of heart to the DC components of RED wavelength which tells about the intensity of light as the intensity increases so does the Small AC signal and this answer is divided by the AC to DC ratio of Infrared wavelength. The ratio R is used in the following equation to determine the Percentage of oxygen blood saturation levels. A similar implementation pulse oximeter using PIC18F452 microcontroller is presented, the design contains a Red and Infrared LED which are turned on and off alternatively using a 1 KHz wave and in this approach, sample and hold circuit are used to sample output of respective LED which increases circuit complexity and cost [15]. This method is used universally by using the curve between the ratio and saturation levels of the existing sensors [15].

$$SpO_2=110-25(R) \quad (2)$$

A small calibration is required in the equation (2) due to the fact that each new design has slightly different phototransistor sensitivity, different wavelength of Red and Infrared. As pulse oximeter has two LEDs, there can be two phototransistors depending upon the location i.e. as a ring structure [16].

Transmission type oximeter have LEDs and phototransistor on the opposite sides as compared to reflection oximeter which have both LEDs and phototransistor on the same side, the reflectance type oximeter consumes less power as they don't have to pass through the body tissues and a reflectance oximeter design which uses a low power Microcontroller with minimum circuitry and small high intensity LEDs is presented and preferred as pulse oximeters are widely used in ICUs to continuously monitor patients health for days at a time and using minimum power could be additional advantage[17-18]. In Ref. [19] is presented a military applications of reflective pulse oximeter embedded into soldiers' helmet for monitoring real time heart rate level of blood saturations of soldiers in the battle fields.

PIC16F477A microchip is used in [20] to design digital thermometer but with one limitation which is to insert a constant to be multiplied for the thermometer to output analogue value corresponding to temperature, one solution for this in explored in [21] which using Ds18b20 to converts the temperature value automatically outputting result in digital format. Pulse Oximeter output is very sensitive to motion and usually the part of body has to be kept steady for correct measurement of the oxygen saturation levels [22].

A unique approach of measuring the oxygen saturation levels by monitoring the colour of blood rather than measuring the ratio of absorption of different wavelengths is presented which also utilizes Arduino as main platform [23]. Approaches to measure the heart rate, temperature and pulse oximeter using various techniques, using buzzers to warn if a particular threshold is crossed i.e. heart rate dropped to certain level or transmitting them using RF communication to servers is presented and analysed [24-26].

The Newest Samsung mobiles are using pulse oximeter and heart rate sensors to which Samsung has given S health name [27]. They use a built in Samsung S health app to monitor blood oxygen saturation levels and heart beat rate. Typical value of pulse oximeter could have error rate of 4% but an oxygen level below 90% is considered low, resulting in hypoxemia [28] that is why a value of 85% oxygen level is considered alarming. Arduino has become a popular platform due to its reliability, simplicity and low cost. A lot of sensors and devices are already available in market with which can easily be connected with Arduino [29].

II. DESIGN AND IMPLEMENTATION

The sensing part of the pulse Oximeter and heart rate consists of Light emitting diodes of wavelength 640nm (red) and 940nm (infrared). These LEDs are turned on and off alternatively. The transmittance light from the LED passes through the body part e.g. Fingers and absorbed by varying blood flow caused by heart heats before being detected by the phototransistor. The phototransistor produces a large DC signal which is a measurement of average light being shined by LED plus a small AC signal resultant of heart contraction and expansion.

The proposed design presented in this paper turns on RED and Infrared LEDs alternatively for 5 second time period. When red LED is turned on input is given to the Dc components of the ADC of microcontroller (uC) which measure the intensity of LED, the microcontroller controls the intensity of the LEDs using a pulse width modulation (PWM) technique, the LEDs are connected in common Emitter configuration which is used here as a switch, by varying the on/off period of the PWM uC adjusts the DC output to establish a baseline so that a different finger width or skin tone doesn’t effects the results.

The DC components is also used to calculate the ratio of RED light transmitted through body part. The AC signal is filter out using combination of Low pass passive RC filter and high Active Operational amplifier filter (Op-Amp) which also amplifies the output to 1-3V which is used as input to sample and hold circuit controlled by uC to measure the output and given as an input to another ADC of microcontroller. The microcontroller calculates average of AC and DC components by taking multiple values of AC and DC components of signal in 5 second time this approach enhances the accuracy because if a single value is disturbed due to some motion, by taking multiple values and averaging them help decrease the effect of any unwanted noise. These values are used to calculate the ratio of Red wavelength. Same process is repeated for Infrared wavelength. In figure 1 we can find the flow chart of the setup. The ratios of Red wavelength AC and DC components to Infrared wavelength AC and DC components are used to calculate proportion of Red wavelength to Infrared wavelength being absorbed by the blood by turning on the LEDs alternatively. It is important to measure the DC component because it is the measure of intensity of LED which is producing the small AC signal and it depends upon the intensity.

The sensing part of the circuit (figure 2) consists of 2 LEDs and one photodiode which forms a transmission type oximeter which has Red and Infrared LEDs on the opposite side of the phototransistor. The LEDs are connected to the collector of NPN bipolar junction transistor (BJT) used a switch designed so that a maximum current of 20mA flows through. The switch is controlled via uC PWM input at the base of each BJT, the on time of PWM increases the intensity of LED and hence more light passes through the finger but the baseline is established so that the PWM is increased and decreased to get same level of intensity of LED passing through the finger.

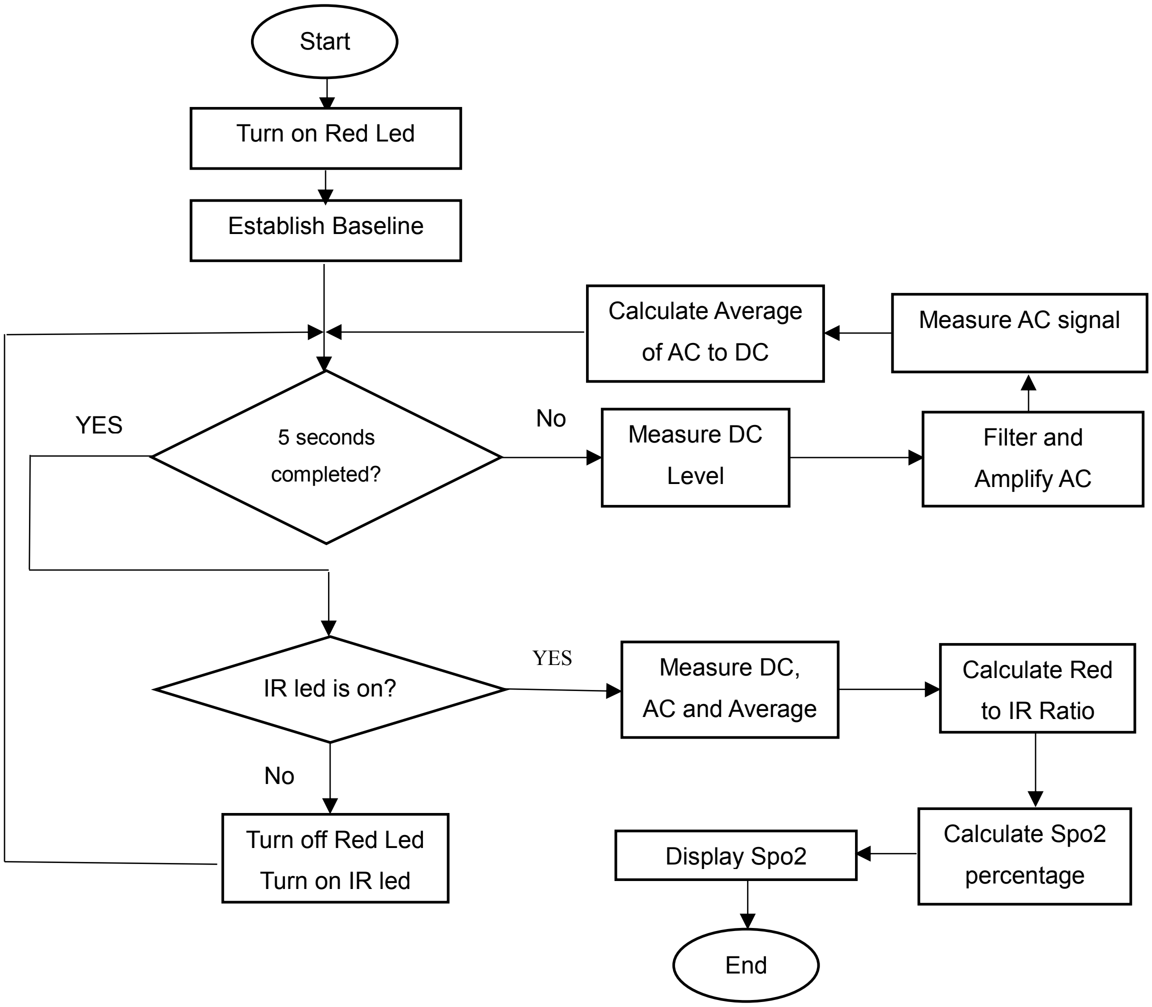

Fig. 1 Flow chart of process ratio of red and infrared wavelength

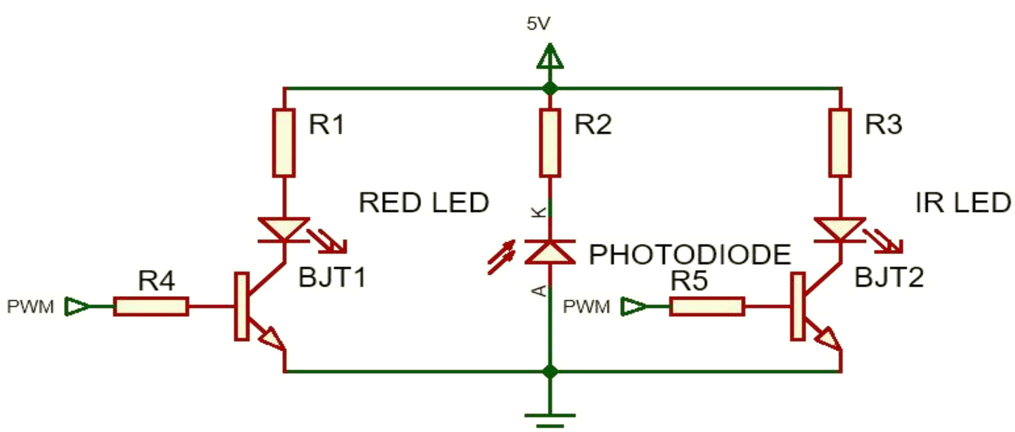

Fig. 2 LEDs Driver and sensing part

The signal conditioning and sampling circuit is shown in figure3, the output obtained from phototransistor is filter out by high pass filter with cut off frequency of 0.5Hz which removes DC completely, this output is then passed through LM 358 op-amp amplifier used as non-inverting Active low pass filter with cut-off frequency of 10Hz and gain of 150 blocks high frequency noise or oscillations in circuit.

Arduino turn its led control pin on and off repeatedly to control the intensity of wavelength using PWM pins of the Arduino board, so it does not cause the output at phototransistor to be very low or high.

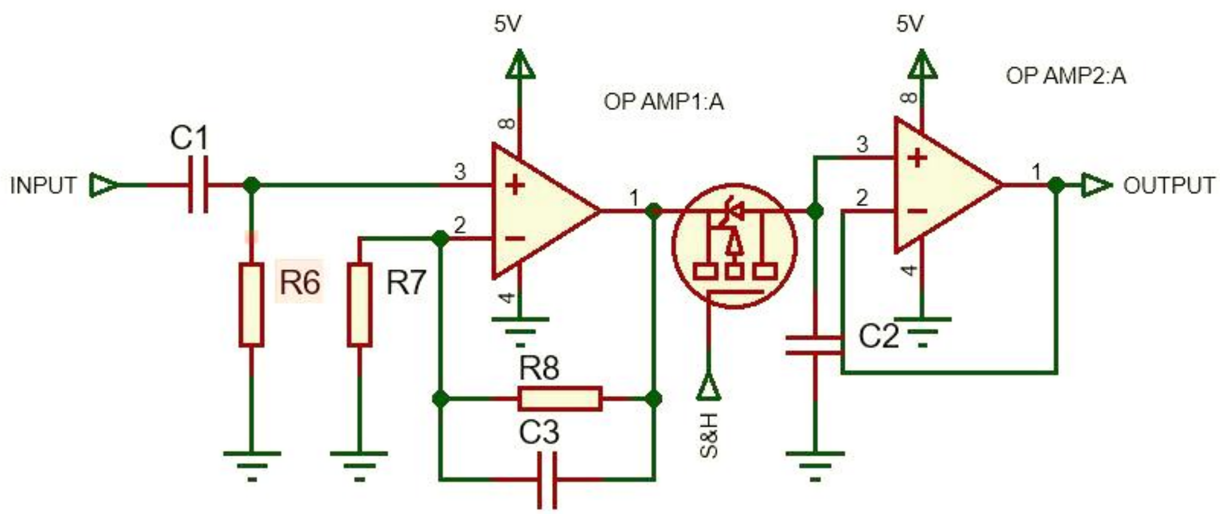

Fig. 3 Conditioning & Sample/ Hold Circuit

The output waveform obtained after the Amplification stage is shown in figure 4, using the Arduino IDE serial plotter function [30, 31], the high frequency noise is due to the Pulse width modulation input to the LED, it is eliminated using Arduino library of digital filters. The output is sampled and hold before Arduino analog pin reads, it is using NMOS based Sample/Hold The NMOS samples input of amplification stage when Arduino set the gate to 5V and holds the output, when the output is 0V the Sample/hold Circuits only hold value correctly for milliseconds before the capacitor discharges through the MOSFET.

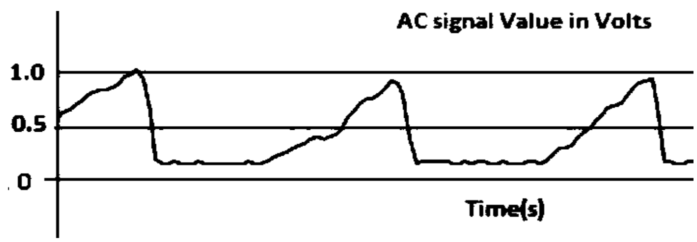

Fig. 4 Amplification output

The block diagram of embedded Health monitoring system is shown figure 5 where the pulse oximeter output is displayed on 16x2 LCD. The output of the AC signal is measured when the PWM pin is maximum when the finger is shinned, the high and low voltage level of AC wave are measured to calculate the heart rate. A small DS18b20 digital thermometer is attached to Arduino which determine the body temperature as well. In this way, a small heath monitoring embedded system is designed which can be used by clinics or at home to determine the body temperature, heart rate and blood oxygen saturation levels.

SPo2 equation is adjusted because of the fact each new design has LEDs with slightly different wavelength and phototransistor with different spectral sensitivity. It is done by comparison of designed pulse Oximeter with Samsung S health sensor [30].

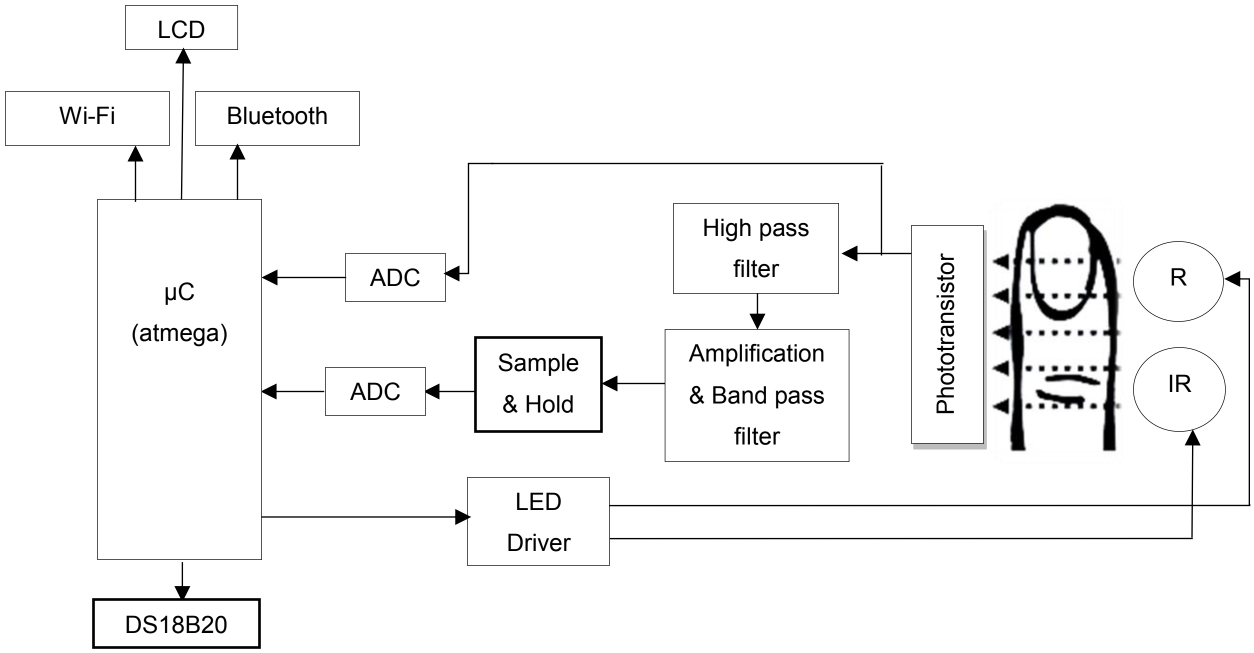

Fig. 5 Health Monitoring Block Diagram

The Sensor used for temperature measurement of body is DS18b20 which is 1 wire digital thermometer it senses and transmits temperature automatically with the need of Analog to digital converter (ADC) and Arduino DS18bs0 library is used to retrieve temperature and display it on LCD [31].

In figure 6 an image of the full embedded system. The system uses Bluetooth module HC-05 [32] and Arduino Bluetooth terminal application [33] to send measured vitals and data via Bluetooth to the android phone. The application receives the data at 9600 baud rates so HC-05 is configured to work at that data rate. The embedded system is uploading the sensor values it measuring to the internet so that it can be remotely monitored by physician or other staff. The interval can be varied depending on the requirement.

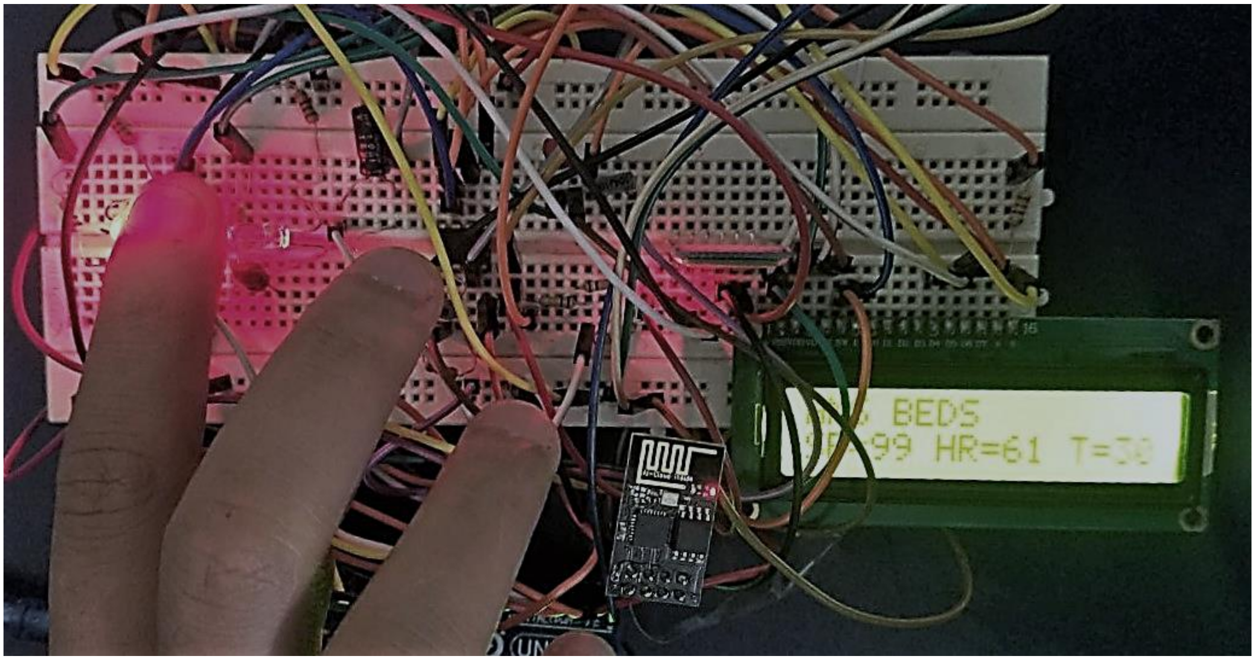

Fig. 6 Prototype

The vitals are also updated via WIFI module ESP8266 [34] to internet in a cloud-based system where different module can update their data and can be viewed by a physician or concerned person though internet without the need to visit it personally thus forming an internet of things architecture of different sensors. The architecture for communication is shown in figure 7. The Open Internet of things platform with MATLAB analysis Thingspeak website [35] is used to upload blood oxygen levels, heart rate and temperature in every 10 minutes. The results of the pulse Oximeter are compared with commercially available ChoiceMMed model PO10 pulse oximeter [36] shown in figure 8, which is normally used by physicians as a well-used portable device. The maximum SpO_2 error rate is 2% which is within acceptable error rate as normally a saturation level below 85% is alarming. Similarly, the heart rate is measured in five beats and averaged to give beats per minute.

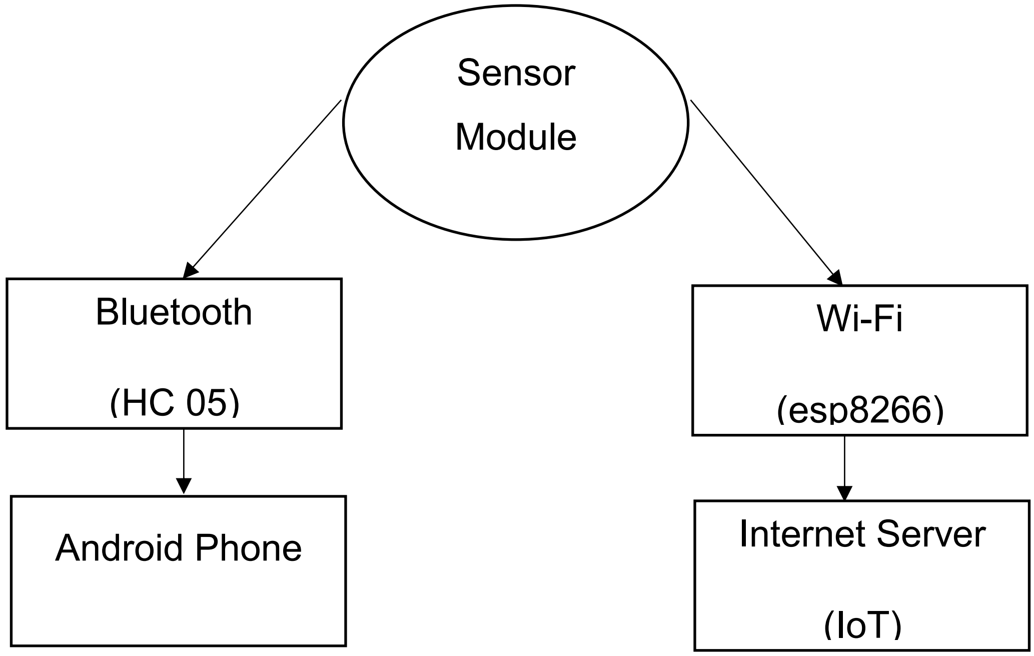

Fig. 7 Communication Protocol

III. RESULTS

Heart rate and oxygen saturation levels of five different persons are compared between prototype and ChoiceMMed Sensor.

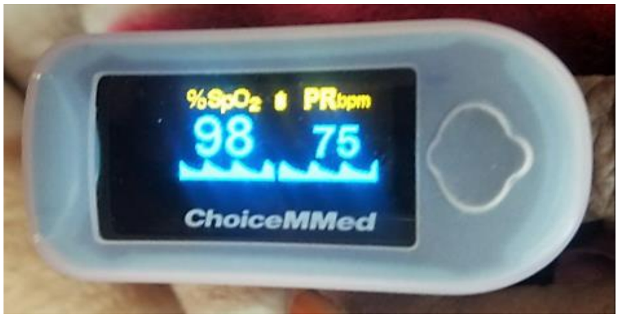

Fig. 8 ChoiceMMed PO10

Subject No.	SpO_2 Prototype Reading	ChoiceMMed Model PO10 Reading
1	97	97
2	96	97
3	100	98
4	95	96

5	93	95

Table I. ChoiceMMed Vs Prototype Pulse Oximeter Prototype Readings

Subject No.	Heart rate Prototype	ChoiceMMed Model PO10 Reading
1	76	72
2	60	65
3	81	76
4	73	73
5	59	62

Table II. ChoiceMMed Vs Heart Rate Prototype Readings

The results are shown in Table I, Table II, results are promising as it is around 5% of difference from the device used by physicians.

Readings	DS18b20 Thermometer Prototype	Medical Thermometer	Error percentage
1	28.25	29.2	3.25
2	31.83	32.1	0.84
3	28.1	29	3.1
4	31.89	32.1	0.65
5	35.23	35.4	0.480

Table III. Medical Thermometer vs Thermometer Prototype

Similarly, the digital thermometer prototype output compared with medical thermometer and shown in the table III. The maximum error percentage is 3.25% with the average around 1.3% which is acceptable for the temperature sensor.

The results are updated to internet Server Thingspeak which visualized graphs with readings vs time for SPo2, heart rate and temperature respectively. As shown in the figure 9, each vital is shown in different line graph and the variation over time can be seen thus making an Internet of things platform for the designed embedded system. The measured vitals are transmitted to android application as shown in the Figure 10 so that the embedded system can communicate with smart phone where the user can see their vitals.

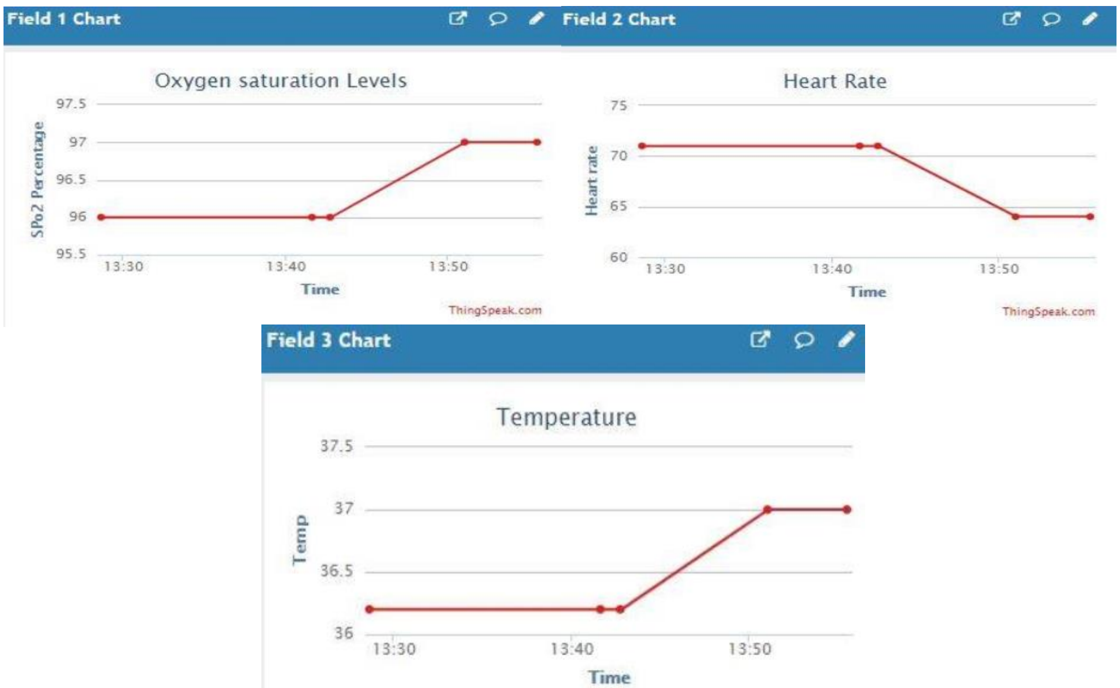

Fig. 9 SpO_2, Heart rate and temperature readings on Internet Server

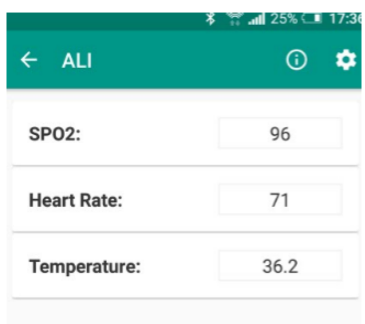

Fig. 10 SPo2, Heart rate and temperature reading on android phone

The result of the designed SpO_2, heart rate and temperature sensors are compared with ChoiceMMed Model PO10 (SpO_2 , Heart rate) and Medical Thermometer and displayed in figure 11 below.

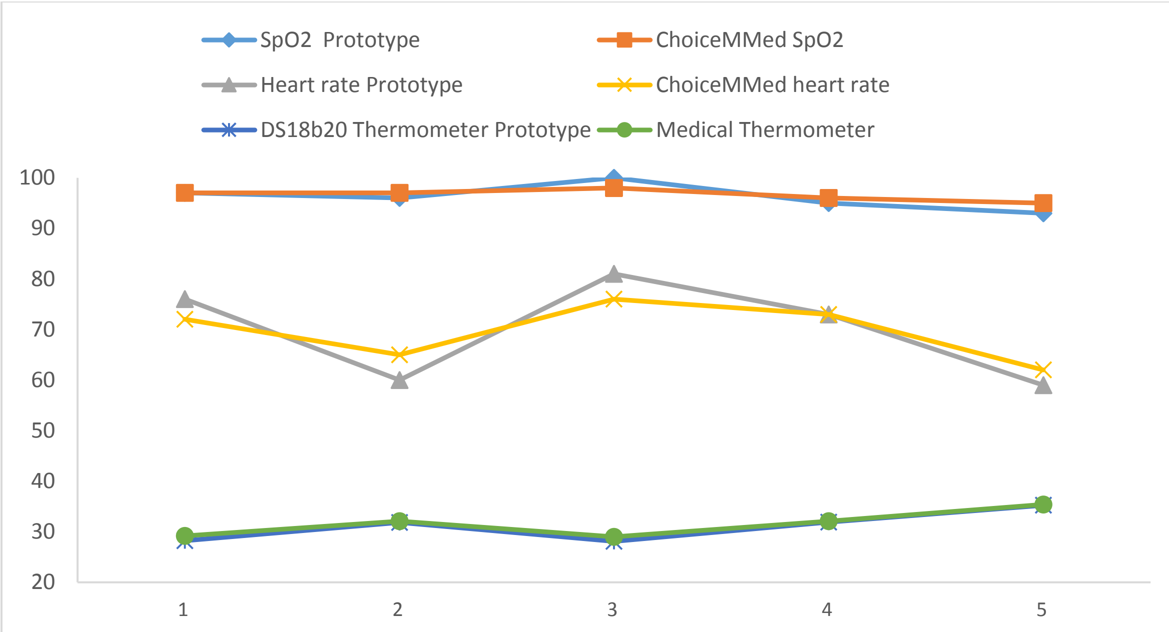

Fig. 11 SpO2, Heart rate and temperature comparison

VI. CONCLUSION

An internet of things embedded low-cost Health monitoring system is designed and implemented using Arduino Uno board. The system uses a combination of pulse oximeter, heart rate and temperature sensors to measure important human vitals continuously and non-invasively. A small digital DS18b20 thermometer is added so that the embedded system is able to measure temperature. The system uses a figure probe to calculate blood saturation levels, heart rate and temperature of the body. A transmission type methodology is followed to design a pulse oximeter, LED driver circuits and sample/Hold circuits are used to increase Accuracy of pulse oximeter which calculate blood oxygen saturation levels and heart rate. The pulse oximeter results are compared to a commercially available ChoiceMMed Pulse Oximeter and a maximum deviation of 2% is observed which is acceptable. The system calculates the heart rate and body temperature with high accuracy. The system is to be used for continuous monitoring of human vitals especially for elderly population at home. ESP8266 WIFI shield is used to connect the designed embedded system to the internet server to update the measured values to the internet. The measured vitals are shown using on board Liquid crystal display and transmitted to android smart phone using HC-05 Bluetooth module with Arduino.

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