I J C T A, 10(9), 2017, pp. 831-841 ISSN: 0974-5572

Remotely Accessible Microcontroller Based Health Monitoring System

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ABSTRACT

Recent developments in the field of biomedical instrumentation have not only improved the lives of countless people but also have redefined the medical profession. There are devices coming up for the better diagnosis and treatment of patients that use non-invasive techniques. Non-invasive measurement ensures painless operation with continuous monitoring and very less chances of infection. A system measuring vital health parameters continuously gives a complete picture of the patient's body functioning in real time. In this paper, we develop a system to measure health parameters like body temperature, pulse rate and blood oxygen saturation of a person continuously, display the values locally and indicate if the values lie in the normal range or not. The measured values are also uploaded to cloud from where the patient's database can be exported. If the health parameters fall beyond the normal range, an SMS is sent to the concerned doctor for immediate attention.

Keywords: NXP LPC1768, photoplethysmography, SpO_2.

1. INTRODUCTION

Body temperature, respiratory rate, blood pressure and pulse rate constitute the four primary vital signs that are used to check the normal functioning of the body. Non-invasive measurement has many advantages over its counterpart such as pain free and infection free practice. Other advantages include avoiding handling of blood and needles, easy and efficient operation, continuous and precise measurement with immediate results. Blood oxygen saturation is now considered as the fifth vital sign as it is used widely in operating rooms, critical care and ambulances. In this paper, we implement a system that is capable of measuring the body temperature, pulse rate and blood oxygen saturation of a person and check if the values lie in the normal range.

Measurement of temperature is suggested by the National Institute of Clinical Excellence as a portion of initial assessment in case of acute sickness (NICE, 2007) and is recommended for post-operative management by the Scottish Intercollegiate Guidelines Network (SIGN, 2004). The reason why temperature measurement is important is that a number of diseases are followed by characteristic changes in the body temperature. In [1], a system is proposed to measure the body temperature of a patient. The system makes use of an LM35 temperature sensor, which converts temperature into a voltage signal. This voltage signal is given to a microcontroller, which calculates the body temperature using suitable algorithm. In our system, instead of the regular LM35, we make use of a TI temperature sensor LM35AH that has a special metal casing for precision temperature measurement.

Pulse rate is the measure of number of heartbeats in a minute. It not only measures the heart rate but also indicates the strength of the pulse and heart rhythm. The normal range for pulse rate is 60-100 beats per minute. Blood oxygen saturation is the percentage of hemoglobin that carries oxygen.

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As we breathe in oxygen, it enters our lungs and then gets passed to various organs of the body via blood by the means of hemoglobin. The hemoglobin carrying oxygen is the oxygenated hemoglobin and the hemoglobin carrying no oxygen is deoxygenated hemoglobin. Thus, the ratio of percentage of oxygenated hemoglobin over the percentage of total hemoglobin gives the oxygen saturation of blood.

$$SpO_2 = \frac{[HbO2]}{[HbO2]+[Hb]}*100\% \quad (1)$$

Pulse oximetry is a non-invasive technique that uses light to calculate the blood oxygen saturation. The systems mentioned in [2], [3] and [4] make use of a light source (LED) and a light detector (photodiode). When a finger is placed between the LED and the photodiode, a part of light is absorbed by the finger and another part is transmitted which is detected by the photodiode. The light absorption by the finger depends on the wavelength of light, the optical path which is travelled by the light and the concentration of absorbing surface. There are laws which govern the absorption of light. Beer's law states that the light absorbed by the finger is more if the concentration of surface absorbing light is more. So, more hemoglobin in a unit area will absorb more light. Again, more hemoglobin is present in a wider artery compared to a narrow one, so more light is absorbed in case of a wider artery. Lambert's law states that the light absorbed is greater if the path travelled by light in the absorbing surface is more. So, combining the two laws in [2] to get Beer Lambert's law, which is:

$$\frac{1}{Io} = e^{-\varepsilon CL} \quad (2)$$

Here I = light transmitted, Io = light incident, L = Optical path length, C = concentration and ε = molar absorptivity. From fig 1, it is clear that oxygenated hemoglobin absorbs more of infrared light than the red light while the deoxygenated absorbs more infrared light. This feature of absorption at different wavelengths is used in pulse oximetry.

Using these properties, we have designed a PPG sensor to calculate pulse rate as well as blood oxygen saturation. The sensor which we developed uses TI photodiode OPT101 instead of the regular photodiode. OPT101 has an inbuilt trans impedanceamplifier, which converts the current output of the photodiode into a voltage signal thus avoiding an extra current to voltage converter circuit.

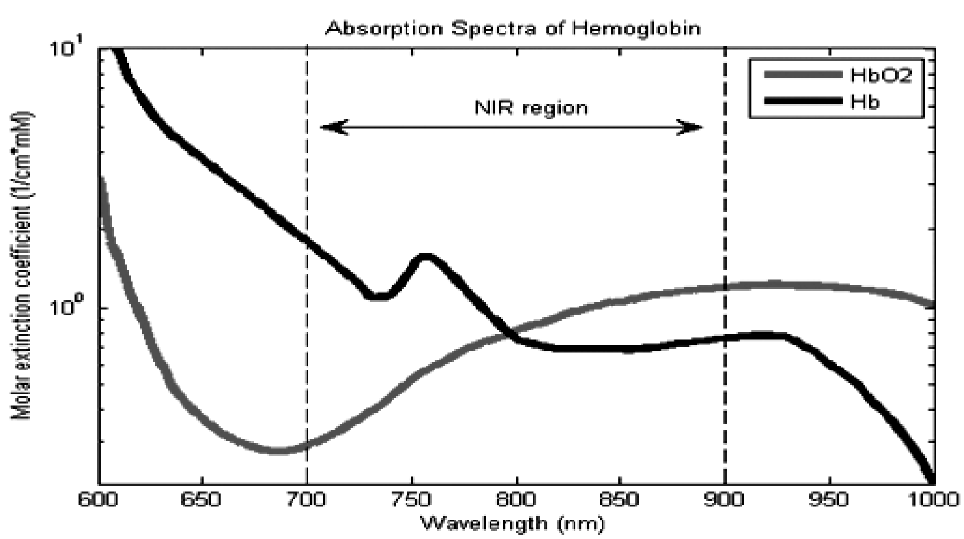


Figure 1: Absorption spectra (Courtesy:https://commons.wikimedia.org/wiki/File: Oxy_and_Deoxy_Hemoglobin_Near-Infrared_absorption_spectra.png)

A single device which measures all these parameters and in addition to local display, access to these values from a remote place would be of great help to the patient as well as doctor. Thus, we have developed a device, which measures vital health parameters like body temperature, pulse rate and SpO_2 values. Calculated values are displayed on an LCD and uploaded simultaneously to cloud (Thingspeak.com) where a graph is drawn against real time. The values uploaded can be accessed remotely and exported to an excel sheet. These values are monitored continuously and an SMS is sent via Way2SMS to the doctor in charge for immediate attention in case the values are not normal.

2. SYSTEM REQUIREMENTS

The developed system makes use of the following components:

2.1. Microcontroller

The microcontroller used is NXP LPC1768, which is an ARM Cortex M3 based microcontroller with a 32-bit core running at 96MHz. It features 512KB FLASH, 32KB RAM along with a lot of interfaces including a built-in Ethernet, USB Host and Device, SPI, I^2C, CAN, DAC, PWM and other I/O interfaces. It has a 12-bit on-chip ADC with power down mode. The microcontroller has a drag and drop feature to burn the code and a lot of online tools with the board powered as a USB drive packaged as a small DIP form-factor. We programmed it with online mbed compiler in C language.

2.2. Photodiode

The photodiode used for the PPG sensor is TI OPT101.OPT101 is a monolithic photodiode with a built-in transimpedance amplifier. The photodiode converts the received light into current, which is then converted into corresponding voltage by the amplifier. The unique package of a photodiode and a transimpedance amplifier on a single IC eliminates the problems encountered in discrete designs, like noise pick-up, leakage current errors and also avoiding the use of an extra converter. The output voltage increases linearly with the intensity of light.

2.3. Temperature Sensor

The system uses TI LM35AH IC for sensing temperature. This TI IC has a special metal casing for precise measurement. The LM35AH temperature sensor is a precision integrated-circuit that gives an output voltage linearly varying with the Centigrade temperature. It has a linear scale factor of 10mV/°C with a range of -55°C to 150°C, an ensured accuracy of 0.5°C at 25°C suitable for remote applications. A voltage between 4–20V can power the sensor. 5V supply from the microcontroller is given as the supply to the sensor. For a 5Vinput, output of the sensor varies between a range of 0-1V for a range of 0-100 degree Celsius.

2.4. Operational Amplifier

Op-amp is a type of differential amplifier required for signal conditioning circuits. The circuits including a filter, an amplifier and a level shifter make use of LM741 op-amp. A dc coupled amplifier with a very high voltage gain, an op-amp basically is a multistage amplifier. Occupying a very less space, 741 is a very good approximation to an ideal op-amp.

3. METHODOLOGY

Fig. 2 shows the block diagram of the entire system:

The entire setup can be divided into two systems: temperature measurement system and pulse rate and SpO_2 measurement system.

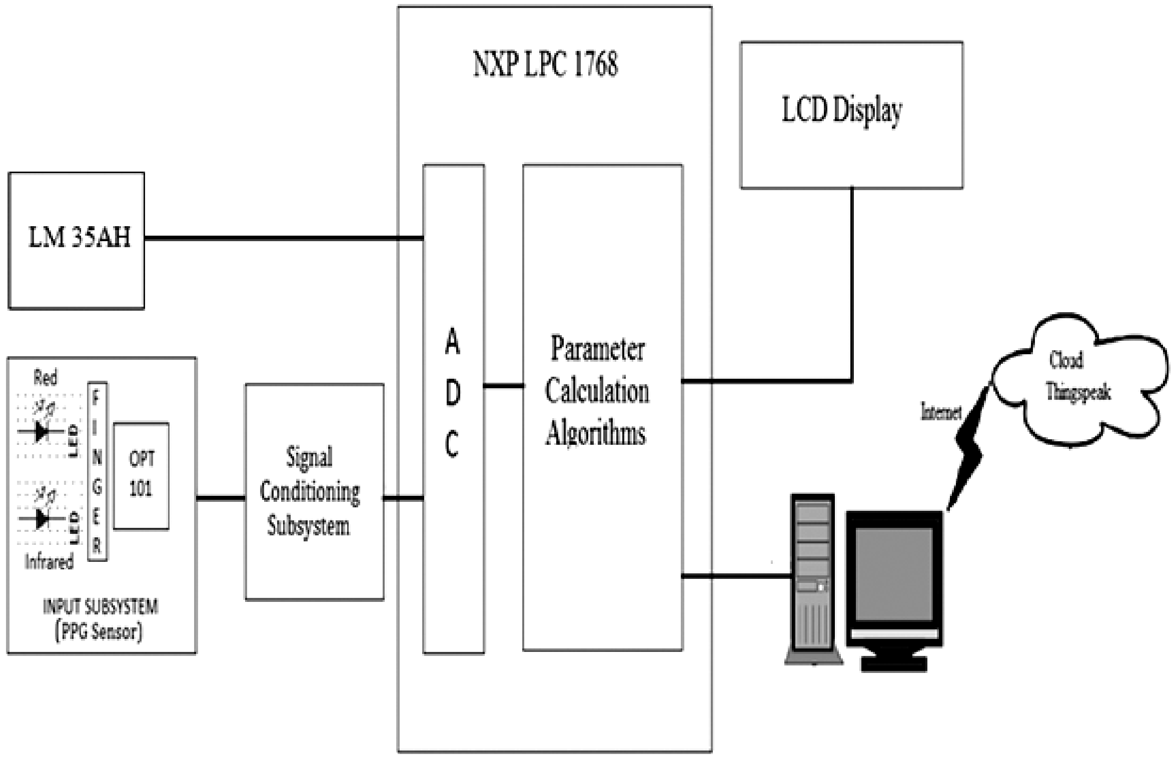


Figure 2: System block diagram

3.1. Measurement of temperature

Temperature measurement system can be further divided into three main subsystems:

- Sensor Subsystem.
- Processing Subsystem.
- Display unit and communication Subsystem.

i) Sensor subsystem: The sensor part for temperature measurement consists of TI LM35AH IC. Since the output voltage range of the IC is between 0-1 V and the range of input voltage the ADC can accept is 0-3.3 V, no signal conditioning is required The output of the sensor can be directly fed to the ADC of the microcontroller.

ii) Processing subsystem: There is a 10mV rise in output voltage of LM35 for 1 ºC rise in temperature. Thus an output of 0V from LM35 corresponds to 0ºC and an output of 1V corresponds to 100 ºC. Relationship between temperature (in degree Celsius) and output voltage is as follows:

$$\text{Temperature} = \text{Output voltage of sensor} * 100$$

ADC of the microcontroller gives a floating point output of 1.0 corresponding to 3.3V and 0.0 corresponding to 0V. Thus the digital converted output of ADC is multiplied by a factor of 330 (3.3 * 100) in order to obtain temperature value in Celsius. Since the body temperature is usually measured in degree Fahrenheit, the temperature value in degree Celsius is converted into degree Fahrenheit by using the following formula:

$$Temp \text{ (in °F)} = Temp \text{ (in °C)} * (9/5) + 32 \quad (3)$$

iii) Display unit: Temperature value thus calculated using above algorithm is then displayed on a 16 X 2 LCD display. Temperature is displayed in both degree Celsius and degree Fahrenheit. Temperature value is also transmitted to a PC through serial communication by UART pins of microcontroller. The PC then uploads these values to cloud (in this case Thingspeak.) where it could be monitored online. The values stored online can also be exported to an excel sheet.

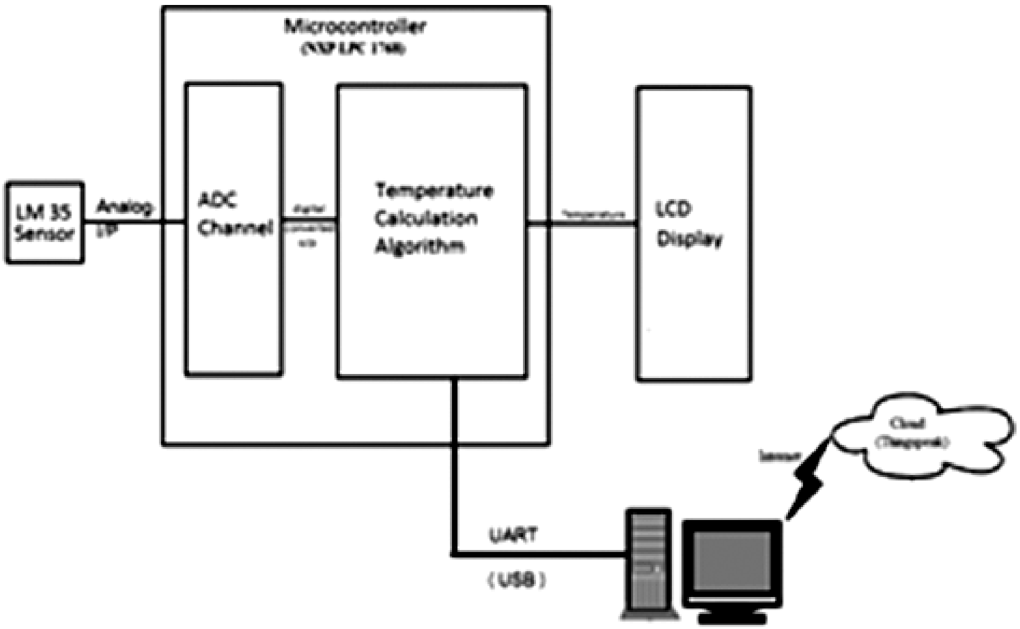


Figure 3: Block diagram for temperature measurement

3.2. Pulse rate and SpO2 measurement

3.2.1. PPG Sensor

As discussed earlier, the PPG sensor consists of a red LED and an infrared LED of 650nm and 950nm (approx.) respectively and a photodiode (OPT101), shown in fig 4. PPG refers to photoplethysmography which measures change in blood volume. The fingertip is placed in between the LED and the photodiode. A part of light transmitted through finger is absorbed (by blood, bones, skin, etc.) while the remaining is detected by the photodiode. OPT101 has an inbuilt transimpedance amplifier that outputs voltage proportional to the light incident on it.

At a time only one of either R or IR LED is turned ON. This switching is controlled by the microcontroller by using a LED driver circuit as shown in fig 5.

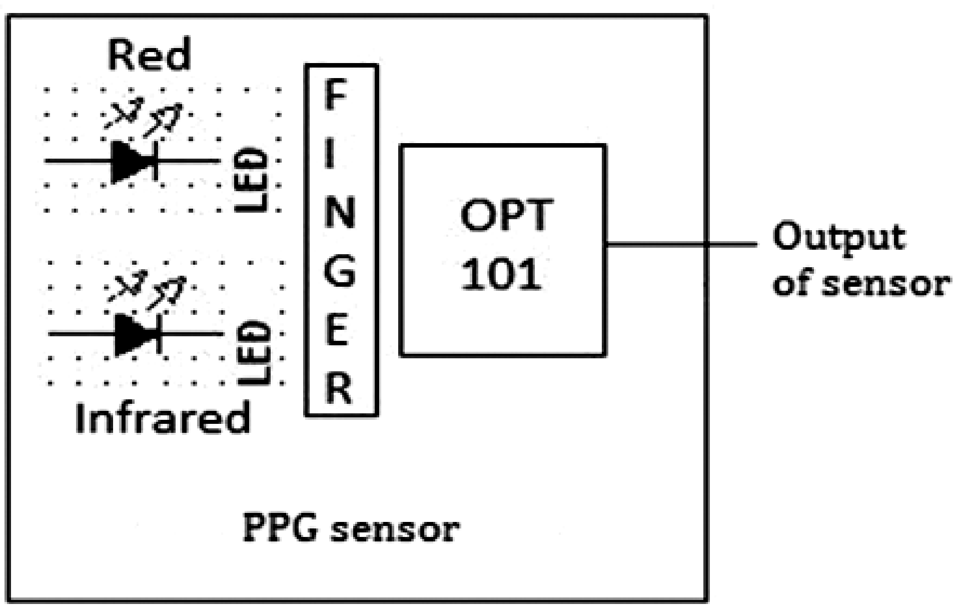


Figure 4: Sensor block diagram

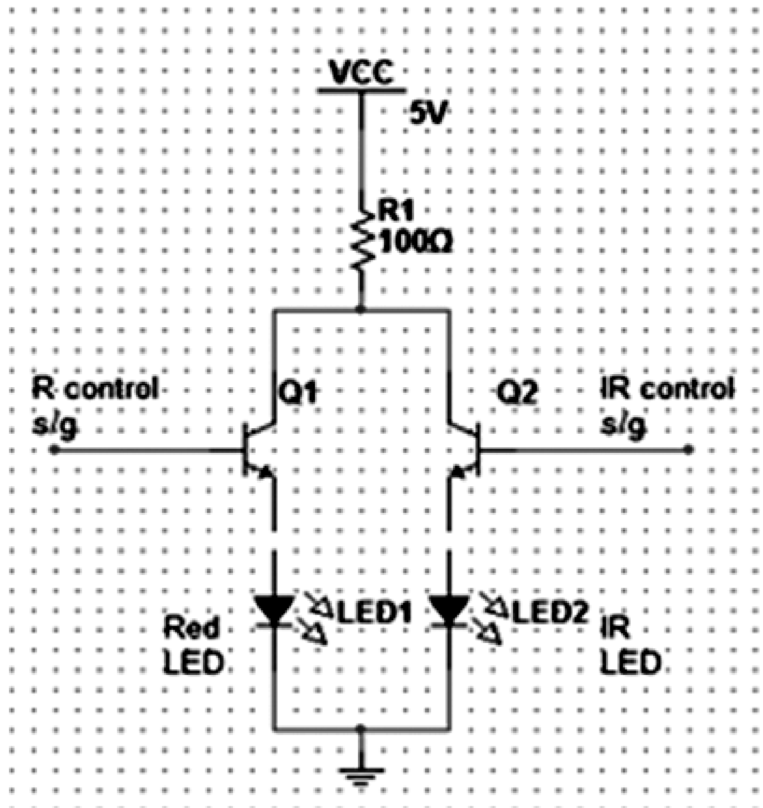


Figure 5: LED driver circuit

3.2.2. Signal Conditioning Subsystem

The arteries contain more blood during systolic phase of heart than during the diastolic phase due to an increased diameter of arteries during the systolic phase. This effect occurs only in arteries but not in veins. For this reason, the absorbance of light in tissues with arteries increases during systole because the amount of hemoglobin (absorber) is higher and the light passes through a longer optical path in the arteries. Thus it can be inferred that AC (pulsating) part of PPG signal is due to absorption by arteries and the DC part is due to absorption by veins, bones, etc.

Thus the PPG signal is first filtered out by a band-pass filter (0.2 Hz to 7.5 Hz) so as to remove the DC offset and interference due to high frequency noise. The resulting signal is then amplified by a non-inverting amplifier with a gain of 51. An offset of 1.7V is then provided by level shifter as the ADC of microcontroller cannot accept negative input signals.

PPG signal seen in second channel of CRO (lower) in fig.6 is the output of amplifier. It can be seen a part of signal lies in the negative region. Signal in channel 1 (upper) is the output of level shifter that is given to the ADC and it can be seen that the signal lies between 0 and 3.3V.

3.2.3. Calculation of Pulse rate and SpO_2

The digital converted PPG signals of R and IR LEDs are then stored in the form of arrays for further analysis. In order to calculate pulse rate, number of peaks are calculated for IR PPG signal and the value is then multiplied by 6 (since IR LED is ON for 10 seconds). IR LED is chosen over R since the IR PPG signal's magnitude is more than that of R and the algorithm was found to work better on it because of the same reason.

In [2] it has been deduced that a factor called Ratio of ratios 'R'can be used to calculate SpO_2. It has been found that with an increasing value of R, SpO_2 decreases linearly. Thus in order to calculate SpO_2, R values are calibrated against SpO_2 in order to obtain an equation between them.The formula for R is:

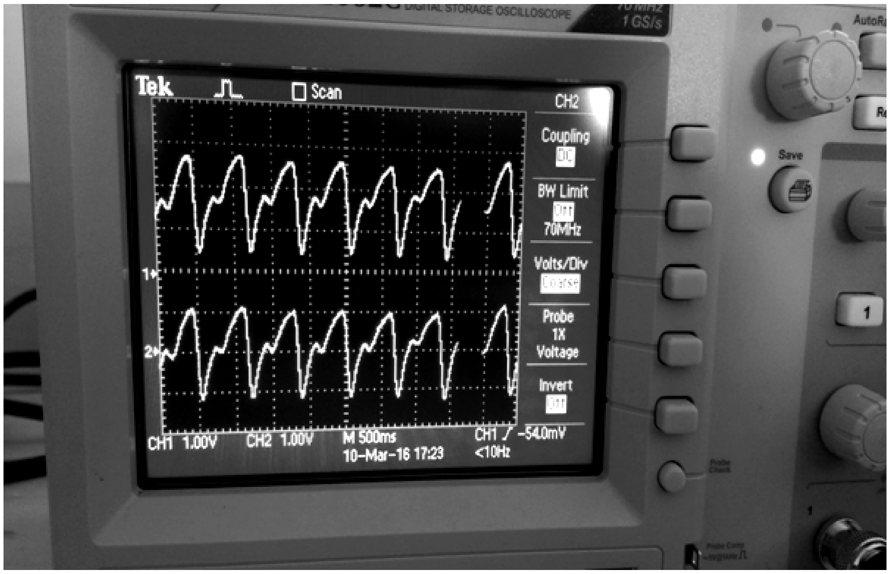


Figure 6: Filtered PPG signal

$$R = \frac{AC(Red)/DC(Red)}{AC(IR)/DC(IR)} \tag{4}$$

Where AC corresponds to pulsatile component (peak to peak voltages) of Red and Infra-red LEDs. The R value obtained was calibrated against SpO_2 values obtained using a calibrated pulse-oximeter. Thus using regression analysis, a relationship was obtained between R and SpO_2. Thus the microcontroller calculates SpO_2 by substituting the calculated R value in this equation.

3.2.4. Display and communication Subsystem

SpO_2 and pulse rate values thus calculated are displayed on a local 16 X 2 LCD display. The parameters are also transmitted to a PC through serial communication by UART pins of microcontroller. The PC then

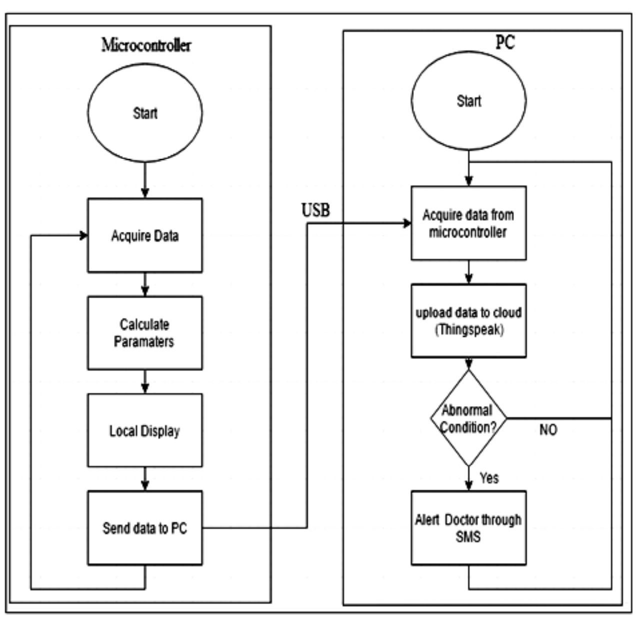


Figure 7: Overall system flow

uploads these values to cloud to enable online monitoring. If the pulse rate or SpO_2 values are found to be abnormal, an SMS alert is also sent to the Doctor in charge of the particular patient.

4. RESULTS

4.1. Temperature calculation and local display

Table 1
Temperature validation results

Sl. No	*Temperature (Thermometer)*	*Displayed Temperature*	*% Error*
1	35ºC	34.7ºC	-0.86 %
2	35ºC	34.6ºC	-1.14%
3	36ºC	36.64 ºC	1.77 %
4 (Room temp)	31.5ºC	31.99 ºC	1.55%

From Table 1 it can be deduced that the system calculated the temperature fairly accurately.

Figure 8: Local display of temperature in Celsius and Fahrenheit

4.2. Pulse rate calculation results

Table 2
Pulse rate result validation

Sl. No	*Pulse rate (BPM) calculated*	*Pulse rate (BPM) from pulse oximeter*	*% Error*
1	96	98	-2.04
2	72	71	1.4
3	96	97	-1.03
4	72	73	-1.37
5	90	87	3.44
6	90	92	-2.17
7	78	76	2.63
8	108	109	-0.91

Pulse rate values obtained by the system were validated with the pulse rate values obtained by a pulse oximeter and the results are stated in Table 2. It can be inferred that the system accurately measures pulse rate value with a maximum error of only 3.44%.

4.3. SpO_2 calculation results

From Table 3 it can be inferred that the system calculated SpO_2 values accurately.

Table 3
SpO_2 validation

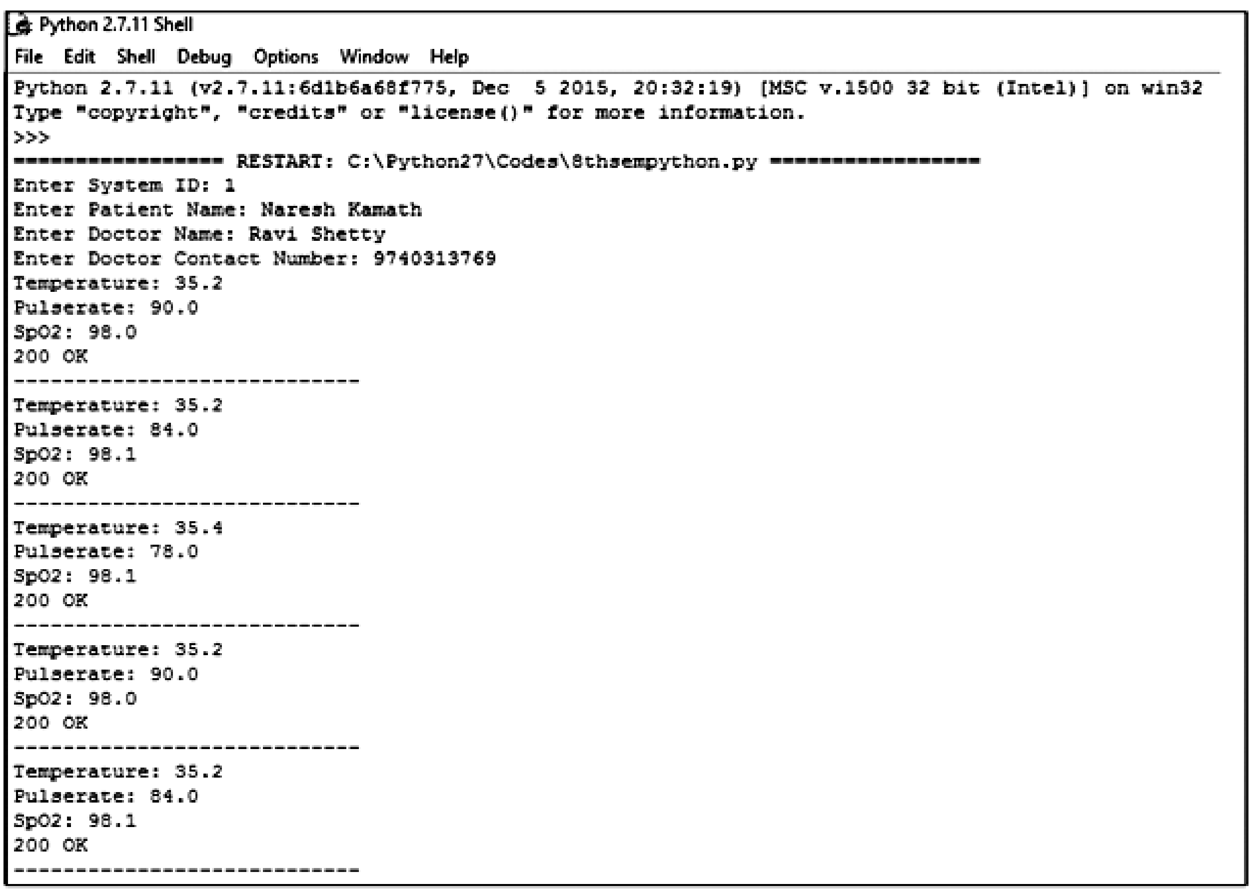
Sl. No.	*SpO_2 (Measured)*	*SpO_2 (from pulse oximeter)*
1	98.22	98
2	98.47	98
3	98.46	98
4	97.04	97
5	98.17	98
6	97.86	97
7	98.38	98
8	97.6	98

4.4. Serial Communication

Fig 9 shows the python code running on PC. The python code is responsible for reading the serial data transmitted by the microcontroller and uploading them to cloud. If the pulse rate or SpO_2 values are found to be abnormal, an SMS alert is sent to the doctor in charge of the patient. Information about the patient and doctor in-charge is taken by the python code at the beginning that can also be seen in fig 9.

4.5. Online Parameter Monitoring

Temperature, pulse rate and SpO_2 readings are uploaded to Thingspeak website where they could be monitored remotely. Fig. 10 shows Thingspeak interface where the data could be viewed in graphical form.



```
Python 2.7.11 Shell
File Edit Shell Debug Options Window Help
Python 2.7.11 (v2.7.11:6d1b6a68f775, Dec  5 2015, 20:32:19) [MSC v.1500 32 bit (Intel)] on win32
Type "copyright", "credits" or "license()" for more information.
>>>
================= RESTART: C:\Python27\Codes\8thsempython.py =================
Enter System ID: 1
Enter Patient Name: Naresh Kamath
Enter Doctor Name: Ravi Shetty
Enter Doctor Contact Number: 9740313769
Temperature: 35.2
Pulserate: 90.0
SpO2: 98.0
200 OK
----------------------------
Temperature: 35.2
Pulserate: 84.0
SpO2: 98.1
200 OK
----------------------------
Temperature: 35.4
Pulserate: 78.0
SpO2: 98.1
200 OK
----------------------------
Temperature: 35.2
Pulserate: 90.0
SpO2: 98.0
200 OK
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Temperature: 35.2
Pulserate: 84.0
SpO2: 98.1
200 OK
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Figure 9: Python shell

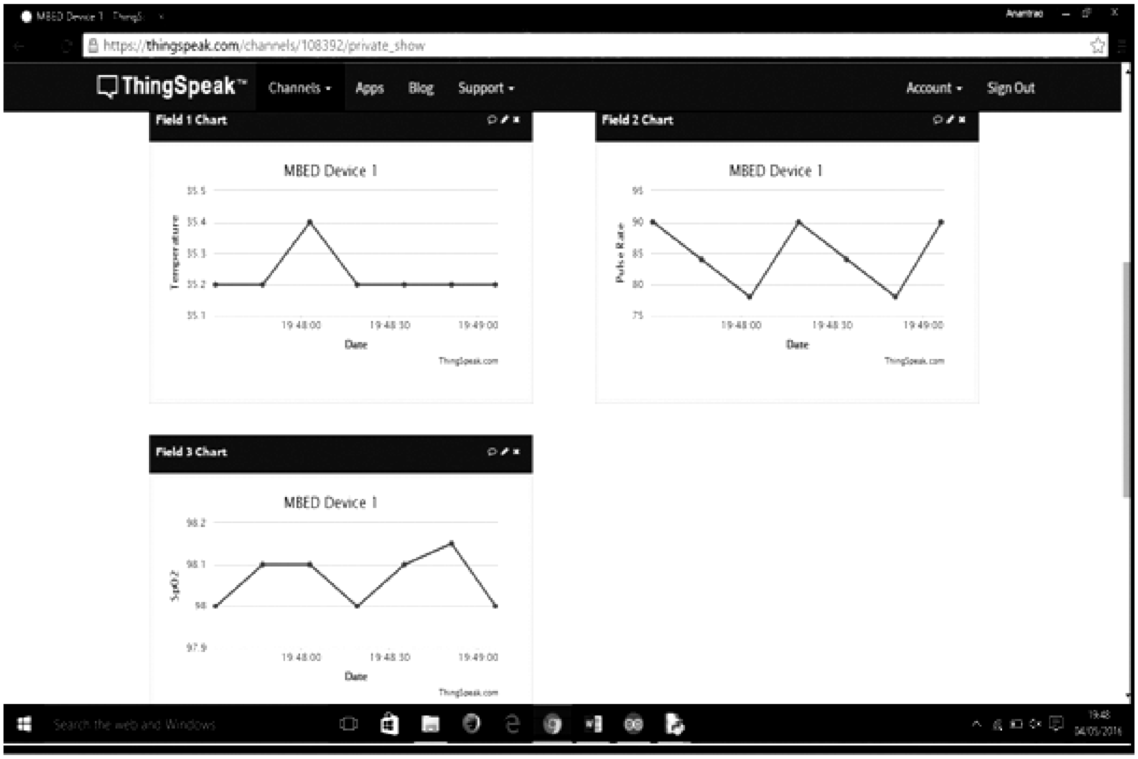

Figure 10: Thingspeak interface

4.6. SMS Alert

In case the pulse rate or SpO_2 values deflect too much from their normal values an SMS alert will be sent to the doctor in charge of the patient. This is done by using an online SMS gateway service. The information about doctor contact number and patient name are taken at the beginning of the python code execution. Fig. 11 shows one such SMS sent because of dropping pulse rate.

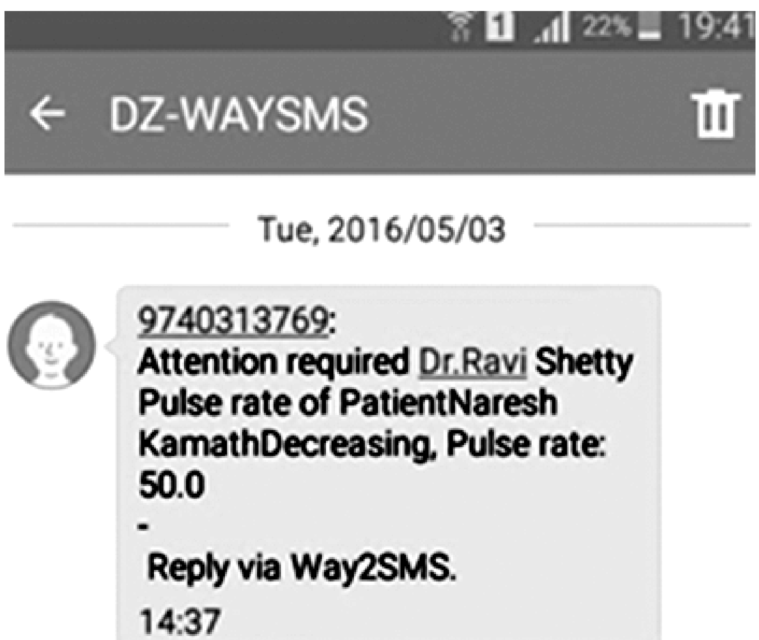

Figure 11: SMS alert

CONCLUSION

In this paper, we have implemented a system to measure vital health parameters i.e. body temperature, pulse rate and blood oxygen saturation. The results obtained are validated and are found to be more or less accurate. We successfully addressed the problems that usually occurs in pulse oximeters with our own design. The system developed is accurate, fast, efficient, easy to use and consistent. The results are displayed locally and online for monitoring and creating database. Whenever the readings deflect beyond the normal range, an SMS is sent to the concerned doctor so that immediate attention can be given.

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