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AN OVERVIEW ON HEART RATE MONITORING AND PULSE OXIMETER SYSTEM

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Abstract- ***Use of technology in healthcare is growing importance as a result of the tendency to acquire chronic disease like heart attack and high blood pressure. Heart rate and blood oxygen saturation is a couple of such biometrics that is monitored in this project to provide information regarding the health of the body. By measuring the intensity change of light transmitted through tissue due to arterial blood, heart rate is measured. Furthermore, oxygenated blood has different light absorption characteristics than deoxygenated blood under red and infrared wavelengths. Comparing the absorptions produce an estimate of the oxygen saturation of blood. The purpose is to examine how heart rate and the oxygen saturation of subject is measured from finger and then processed and displayed. The design, is small in size, easy to use, allows a non-invasive, real time method to provide information regarding health. This enables an efficient and economical means for managing the health care. This document is intended to be used by engineers, medical equipment developers, anyone related to medical practice and interested in understanding the operation of pulse oximeter and heart rate monitoring system.***

Keywords - Beat per minute(BPM), Pulse oxymetry, Oxygenated Hemoglobin (HBO_2), SPO_2, Photoplethismography

I. INTRODUCTION

Measurement of heart rate and pulse oximetry are very important factors to access the condition of human cardiovascular system. Heart rate is formerly measured by placing the thumb over the arterial pulsation, and counting the pulses usually in a 30 second period. Heart rate is then found by multiplying the obtained number by 2. This method although simple, is not accurate and can give errors when the rate is high [1]. In clinical environment, heart rate is measured under controlled conditions like blood measurement, heart voice measurement, and Electrocardiogram (ECG). ECG is one of frequently used and accurate methods for measuring the heart rate. But ECG is not economical [2]. The heart rate of a healthy adult at rest is around 75(±15) (or greater for females) beats per minute (bpm). Athletes normally have lower heart rates than less active people. Babies have a much higher heart rate at around 120 bpm, while older children have heart rates at around 90 bpm. Heart rate varies significantly between individuals based on fitness, age and genetics [3].

On the other hand the percentage of arterial blood saturated with oxygen helps to determine the effectiveness of a patient's respiratory system. The technique by which blood oxygen saturation is determined is called Pulse Oximetry [4]. In earlier days, the common method used to measure blood oxygen saturation was arterial blood gas measurement. An Arterial Blood Gas is a blood test that involves puncturing an artery with a thin needle and syringe and drawing a small volume of blood [5]. This method was invasive, expensive, difficult, painful and potentially risky. So, Pulse Oximeter is introduced, operation of which is non-invasive and based on measuring the absorption of red and infrared light that passes through a patient's finger or ear lobe by using light sensors. Acceptable normal ranges for patients are from 95 to 100 percent, those with a hypoxic drive problem, would expect values to be between 88 to 92 percent. Due to its non-invasive nature, high precision, and reasonable cost, optical pulse oximetry and heart rate measurement system is widely adopted as a standard patient monitoring technique [6]. Diagnosis of heart disease can be achieved by correlating the pattern of measured value with a typical healthy signal, characterizing the measured value with basic logic decisions.

II. LITERATURE REVIEW

According to Handbook of Biomedical Instrumentation by R.S. Khandpur [7], techniques of measuring heart rate are:

Average Calculation:

An average rate is calculated by counting the number of pulses in given time. This method does not show changes in time between beats and thus does not represent the true picture of heart's response to exercise, stress and environment

Beat To Beat Calculation:

This is done by measuring the time (T) in seconds, between two consecutive pulses, and converting the time into beats/min, using the formula beat/min = 60/T.

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Combination Of Beat To Beat Calculation With Averaging:

This is based on four or six beats average. The advantage of this technique over the averaging techniques is its similarity with beat to beat monitoring system.

Pulse oximetry relies on measurement of physiological signal called photoplethismography, which is an optical measurement of the change in blood volume in the arteries.
Pulse oximetry acquires PPG signals by irradiating two different wavelengths of light through the tissue, and compares the light absorption characteristics of blood under these wavelengths. These absorptions obey Beer Lambert's law. According to Beer Lambert's law transmittance of light through the tissue can be calculated using:

$$I_{out} = I_{in}\, e^{A} \quad (1)$$

Where I_{out} is the light intensity transmitted through fingertip tissue, I_{in} is the intensity of the light going into the fingertip tissue and A is the absorption factor[8].

According to Yousuf Jawahar, Pulse oximetry can be done by two methods [9]:

Transmittance Method: In this method, light is transmitted through tissue using the LED and is detected on the other end using a photo-detector. It is more suited to the areas of body that lend themselves better to light transmittance through them, e.g. fingers or ear lobe. This configuration cannot be used in other areas of body when there are obstacles such as bones or muscles.

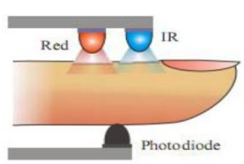

Fig. 1 Transmittance Method

Reflectance Method: In reflectance pulse oximetry it uses a photo detector on the same side as the LED to detect the light reflected by the tissue. This method is more useful where the vasculature is available close to the surface of skin e.g. forehead, wrist, forearm.

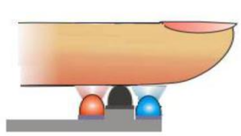

Fig. 2 Reflectance Method

Based on all these review, there are two methods are chosen to calculate heart rate and blood oxygen saturation level.

Heart rate calculation: In this project is based on the beat to beat heart rate calculation process. In this process, number of pulses for a given period T is calculated and converted to bpm by multiplying with 60/T, that gives the instantaneous heart rate in bpm. So this can be expressed as:

$$\text{Heart rate} = \frac{\text{No. Pulses for a given period T} \times 60}{T}\ \text{bpm} \quad (2)$$

Calculation of blood oxygen saturation level: The principle of pulse oximetry is based on the red and infrared light absorption characteristics of oxygenated and deoxygenated hemoglobin. Oxygenated hemoglobin absorbs more infrared light and allows more red light to pass through whereas deoxygenated hemoglobin absorbs more red light and allows more infrared light to pass through. Red light is in the 600-750 nm wavelength light band whereas infrared light is in the 850-1000 nm wavelength light band. The absorption relationship is shown in following figure:

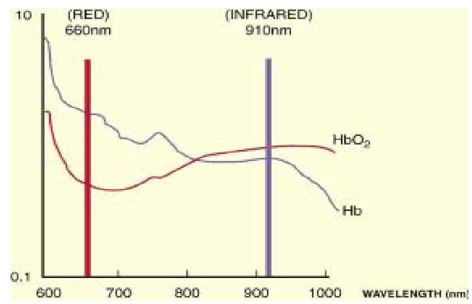

Fig. 3 Absorption Relationship Of Oxygen Levels In The Blood For The Red And Infrared Wavelengths

Because the flow of blood is pulsatile in nature, the transmitted light changes with time. A normal finger has light absorbed from bloodless tissue, venous blood, and arterial blood. The volume of arterial blood changes with pulse, so the absorption of light also changes. The light detector will therefore see a large DC signal representing the residual arterial blood, venous blood, and bloodless tissue. A small portion will be an AC signal representing the arterial pulse. Because this is the only AC signal [10].

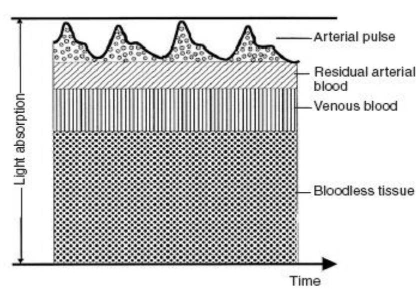

Fig. 4 Light Absorption By Tissue Type

Now the basic formula to calculate oxygen saturation level can be stated as:

$$SPO_2 = \frac{HbO_2}{Hb + HbO_2} \quad (3)$$

Where, hemoglobin with oxygen molecules is considered as oxygenated hemoglobin (HbO_2). When it is carrying less oxygen molecules, then it is considered reduced (Hb).
To find oxygen saturation, first calculate the ratio *R:*

$$R = \frac{\frac{AC\,(red)}{DC\,(red)}}{\frac{AC\,(IR)}{DC\,(IR)}} = \frac{\frac{MAX\,(PPG)\ red}{MIN\,(PPG)\ red}}{\frac{MAX\,(PPG)\ IR}{MIN\,(PPG)\ IR}} \quad (4)$$

The maximum and minimum value will be used to calculate the ratio *R*. Using this value oxygen saturation level can be measured [5]. So, if we consider any linear equation then, the oxygen saturation level can be calculated as,

$$SPO_2 = a - bR \quad (5)$$

Where a and b can be considered as the calibrated values, which are constants.

III. SYSTEM OVERVIEW:

Sensor System:

The optical sensor is consisting of light emitter and detector and control circuit, which are discussed below:

Light Emitter And Detector:

In sensor system, the light source and photo detector are on the opposite sides of the tissue inside a fingerclip. The photo detector measures the intensity of light transmitted through the tissue. For measuring SPO_2 level, it requires two LEDs of different wavelengths to compare the absorption level of oxygenated and deoxygenated blood. Thus the optical sensor is comprised of two LEDs emitting visible and infrared light as emitter and a photo-detector[10].

Control Circuit:

Since both the red and infrared LEDs are detected by the same photodiode, the photodiode cannot distinguish between red and infrared light. But to accommodate this, LEDs is pulsed alternatively[14]. For this purpose, a driver system alternately turns each LED on and off. The device repeatedly samples the photodiode output while the red LED is on, while the infrared LED is on and while both are off. By sampling with both LED's off, the pulse oximeter is able to subtract any ambient light that may be present during measurement[9].For this reason, the RED and IR LEDs are lit alternately every 400ms. The typical pulsating scheme of the LEDs is shown in fig. 6:

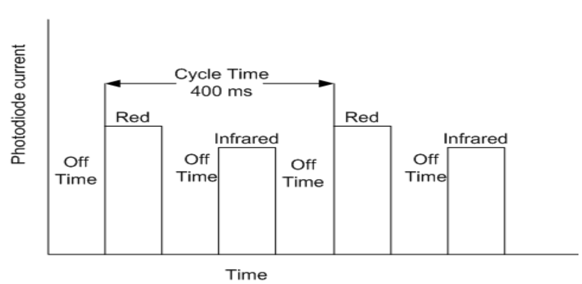

Fig. 6 Typical Pulsating Scheme Of Red And Infrared LED

Pre-Processing:

The input signal is of very low amplitude and the approximately 2% of the signal is of interest. The signal processing is required to separate the desired signal from the steady state signal to give accurate readings. With a proper signal conditioning circuit, little changes in the amplitude of the detected light in sensor unit can be converted into a pulse, suitable for processing by the microcontroller [11].

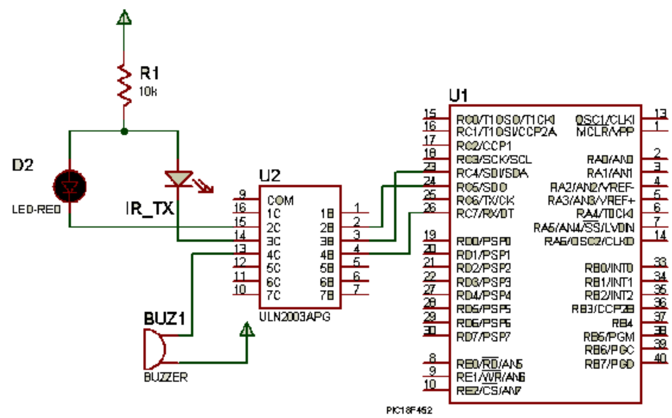

Fig. 7 Control Circuit For Red And Infrared LED

In this project, low power dual operational amplifier LM358 op-amp is chosen. According to its data sheet, it consists of dual op-amps in a single package and it can operate at supply voltages as low as 3.0 V or as high as 32 V with low quiescent currents according to its data sheet. The single stage of this op-amp can achieve voltage swings of 0VDC to common-collector voltage Vcc (pin 8) −1.5V [13].

The gain of OP AMP is calculated as:

$$\alpha = 1 + \frac{R_f}{R_5} = 1 + \frac{680k}{6.8k} = 101 \quad (6)$$

The gain of each stage is set to 101, giving the total amplification of about 10000.

The purpose of the filter circuit is to keep any frequency content between 0-2.5Hz and eliminate above and below this range[11].

The cut off frequency of LPF is calculated as:

$$f_C = 1/(2\pi R_f C_f) = 1/(2\times3.1416\times680k\times0.1e\text{-}6) = 2.34\ Hz \quad (7)$$

The cut-off frequency of active low pass filters is about 2.34 Hz. This means the maximum measurable heart rate is about 2.34×60=140 bpm [12].

There are two stage operational amplifiers configured as active low pass filters. The cut-off frequencies of both the filters are set to about 2.34 Hz, and so it can measure the pulse rate up to 2.34*60 = 140 bpm. A 2.34Hz filter was chosen so that the fundamental and second harmonic of the cardiac beat could be captured.Further the gain of each filter is 100, which gives the total 2-stage amplification of 10000. This is good enough to convert the weak pulsating signal into a TTL pulse [13].

Microcontroller:

To implement the advanced signal processing algorithms on microcontroller in real-time for pulse oximeter and heart rate monitor, the computation involves ratio calculation and look up table implementation to calculate final SpO2 for display. The microcontroller (PIC18F452) is programmed to switch and control the timing and intensity of IR and RED LEDs.

The output signal from the amplifier will be supplied to the PIC18F452 which will be converted from analog signal into digital signal through the built-in ADC. The microcontroller computes the received red and infrared light intensity ratio and hence to derive SpO_2 value. At the same time it calculates the number of beats per minute [14].

Serial Transfer and Display:

For the device to be user friendly, the output is displayed via LCD: SPO2 concentration in percentage and pulse rate in bpm. A 16x2 LCD display is very basic module and is preferred over seven segments and other multi segment LEDs.

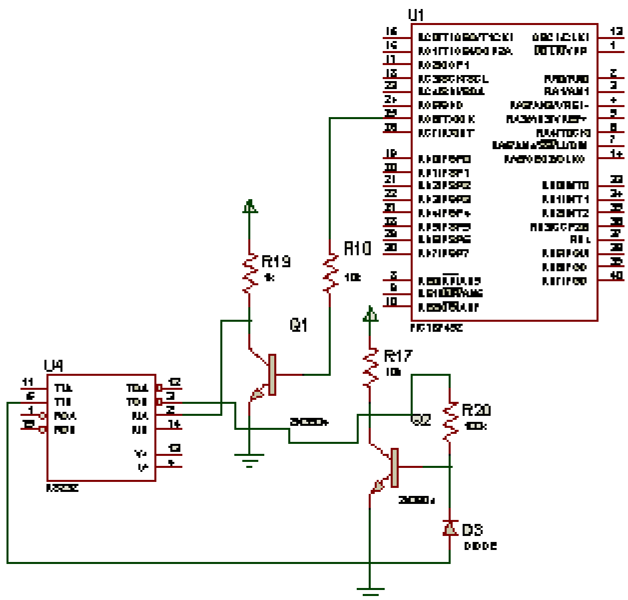

Fig. 8 Serial Transfer

As LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters, animations and so on.

In order to transfer data to the doctor, the users need to connect the system to the PC parallel port.
So the other type of display is a PC serial (USART) port. The microcontroller PIC18F452 has built in USART on board at pins 25 an d 26 (RC6/TX and RC7/RX), that can send data to PC via RS-232 interface and display information of SPO2 concentration and heart rate.

Alarming System :

The output unit consists of an alarming system to indicate whether the heart rate and percentage of oxy-hemoglobin is within the reference values. If the heart rate counter and SPO2 level is different from reference then a LED indicator is lightened and an audio signal is generated. Preset values SPO_2 and heart rate are interpreted by the table I and II:

TABLE I PRESET VALUES OF SPO_2

SPO_2 Reading (%)	Interpretation
95-100	Normal
91-94	Mild Hypoxemia*
86-90	Moderate Hypoxemia*
<85	Severe Hypoxemia*

*Hypoxemia is defined as decreased partial pressure in blood and oxygen available to the body or an individual tissue or organ.

The output of heart rate is compared with the references representing bradycardia and tachycardia for adult or children. These referenced values were taken by statistical computation.

TABLE III PRESET VALUES OF HEART RATE

Age	Heart Rate (BPM)	Interpretation
15 years – adult	< 60	Bradycardia
1–2 days	> 159	Tachycardia
3–6 days	>166	Tachycardia
1–3 weeks	>182	Tachycardia
1–2 months	>179	Tachycardia
3–5 months	>186	Tachycardia
6–11 months	>169	Tachycardia
1–2 years	>151	Tachycardia
3–4 years	>137	Tachycardia
5–7 years	>133	Tachycardia
8–11 years	>130	Tachycardia
12–15 years	>119	Tachycardia
>15 years – adult	>100	Tachycardia

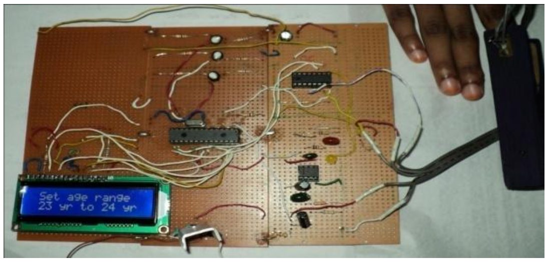

Fig. 11 Physical Appearance Of The Designed Device

IV. CONCLUSION

The Heart rate monitoring and pulse oximeter device available in market are high pricing where the designed device is the cheapest one. The design proposes small size, light weight, low power consumption, standardized signal processing capabilities. This device is able to produce highly reliable test results for both heart rate and SpO2 level. Our designed device has the advantage that it can be used by non-professional people at home to measure the heart rate and SPO2 level easily and safely. At the same time abnormal condition can be detected easily and data can be sent to doctor from PC through email for further diagnosis.

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