PULSE OXIMETER WITH BLUETOOTH INTERFACE

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Abstract - The Pulse Oximeter is a device which measures oxygen saturation percentage non-invasively. This device is one of the applications of analog circuits in biomedical applications. It helps in recognition of hypoxemia and widely used for continuous monitoring in ICU’s. The method employed here is Photoplethysmography. This paper describes the extraction of Photoplethysmogram (PPG) and the signal conditioning required. Feedback compensation which removes patient dependant parameters is discussed in detail. The device is Bluetooth enabled which helps in storing values to PC for future reference and diagnosis.

Keywords - Bluetooth, Patient independent, Photoplethysmogram, SpO₂

I. INTRODUCTION

Pulse oximeter is a non-invasive, portable device used to measure or monitor the amount of arterial oxygen. Pulse oximeter thus measures SaO₂ i.e. oxygen saturation or the amount of haemoglobin saturated with oxygen. When this SaO₂ is measured using pulse oximeter it is termed as SpO₂. Our body needs continuous supply of oxygen. While some of the parts can function without oxygen for some time period, some cannot tolerate even for a short period of time. So, it is necessary to calculate the amount of oxygen carried by arterial blood to assess the functioning of various body parts. So, this is a very important application of analog circuits in bio-medical field.

Oxygen saturation gives a relative measure of amount of oxygen present in a medium. In human body it can be termed as ratio of amount carried by haemoglobin to the maximum content that it can carry. So, it is the ratio of oxyhaemoglobin to the total amount of haemoglobin. Oxygen saturation is represented as percentage rather than as a ratio. It can be given as

\[
\text{SpO₂} = \frac{[\text{HbO₂}]}{[\text{Hb}]+[\text{HbO₂}]} \times 100\%
\]

(1)

Where [Hb] and [HbO₂] are concentrations of haemoglobin and oxyhaemoglobin respectively. (1) assumes that dysfunctional haemoglobin is negligible. A healthy person should have SpO₂ between 94% and 100%. Photoplethysmography technique is used to measure the SpO₂ value. In this technique a part of body is illuminated and the transmitted or reflected light is detected using a suitable photo detector. The signal detected is called Photoplethysmogram (PPG). This technique makes use of two PPG’s to calculate SpO₂. One acquired with red LED (660nm) as light source and the other using IR LED (940nm). In transmittive mode the device is placed at any extremity of body to acquire the PPG, which is usually finger, earlobe etc. In this mode, emitter is on one side and detector is on the other side of the finger. A typical PPG signal has a small AC component superimposed on a large DC level. This DC level is due to absorption of light by skin, tissue, bone, colour of skin and the magnitude changes with individual. The AC component is due to absorption of light due to blood in capillaries which is arterial blood. This AC component has information about blood pressure, oxygen saturation, heart beat etc. The commercially available pulse oximeter are calibrated; some of the devices are USB enabled for storing the value to PC. We improvise these two characters by replacing USB with Bluetooth and device has feedback compensation, thus eliminating the need for calibration of device. Over

Figure 1: Components of typical PPG signal
the years Bluetooth has become the standard for short range communication and is preferred over other wireless transmission methods due to its low power consumption, lower costs and greater signal ability. In some cases they could be used to measure the critical health of a patient, which require it to maintain a stable connection over its wireless range and hence Bluetooth was chosen to satisfy this requirement. Bluetooth would allow for convenient and round the clock monitoring of patients anywhere, where internet access is possible. Through the use of Bluetooth we can pair our device with a wide variety of pre-existing devices like mobile phones, computers etc. which makes the device portable, cheap and versatile. Wireless technology also expands the network of information systems present in the hospitals.

II. DEVICE DESCRIPTION

A. LED and Photo detector:
Two different LED’s are used whose wavelengths are different. Red and IR LED are used for this purpose which emits 660nm and 940nm respectively. The physical significance of these wavelengths is that the difference in absorption of light by Hb and HbO₂ is maximum at one wavelength and nearly same at the other. Thus, they lie on either side of Isobestic point. A suitable photo detector must be placed at other end of finger to measure the transmitted light, from which the PPG is extracted. A Photodiode is used to satisfy this requirement. The assembly of LED’s and photodiode constitutes to sensor. LED is current driven. So, howland current source is used to pump the amount of current required.

B. Switching Circuit:
For calculation of \( \text{SpO}_2 \), we need to send Red and IR light through finger, each for equal intervals of time. But, there is only one photodiode to detect transmitted lights for both the LED’s. This means the information about both the wavelengths is multiplexed into a single photodiode and also the AC component which is used to measure saturated oxygen is time-varying. In order to overcome this difficulty the LED’s are switched alternatively so that only one LED is on at any instant. This switching is done at high frequency (about KHertz) which reduces the time gap between two consecutive switching instants. This arrangement reduces the error incurred due to time gap. The LED’s are thus controlled by SPDT (Single Pole Double Throw) switch whose position is controlled by a self-generated control signal. The control signal is generated by using timer(IC 555). As the switch can flip to two different positions depending on level of control signal, at one position red LED is placed and IR at other. Not only the LED’s are to be controlled but also the signal conditioning circuitry and microcontroller are to be driven by the same control signal so that ambiguity is eliminated. To achieve these IC CD4053 is used which has three SPDT switches.

C. I-V Converter:
The transmitted light through finger falls on the photodiode and it produces current proportional to the intensity of the detected light. This current is fed to an I-V converter to obtain a measurable voltage. Depending on the biasing of photodiode there are two modes of I-V converter. They are photovoltaic mode and the other is photoconductive mode. In photoconductive mode photodiode is forward biased which results in more amount of current generated in photodiode than in photovoltaic mode for same incident light intensity. So, photoconductive mode has high sensitivity which is employed in our project.

D. Low Pass Filters:
The PPG signal is of the order of few hundred milli volts which is buried in noise. In order to remove high frequency noise, a multiple feedback low pass filter of cut-off frequency 2Hz is used. To obtain the DC component of the PPG signal, another low pass filter with cut-off frequency that is 10 times less than that of PPG is fixed, i.e., 0.1 Hz. This DC voltage is used for providing negative feedback which is explained in the next section.

E. Band pass filter:
The frequency of PPG is around 1.2Hz and varies between 1-2Hz. So, the output of low pass filter \((f_c ~2Hz)\) is given to a band pass filter of center frequency 1.4Hz and the 3-dB frequencies of filter are 1Hz and 2Hz respectively. The output of band pass filter is given to a notch filter of 50Hz to remove power line noise if any.

F. Gain stage:
After filtering the signal, it is amplified in order to visualize the low amplitude PPG signal. The output of this gain block is fed to microcontroller to calculate \( \text{SpO}_2 \).

III. PROPOSED FEEDBACK COMPENSATION

One of the major limitations of commercially available Pulse Oximeter is that they need calibration.
This disadvantage is removed by using feedback compensation technique. Pulse oximeter need calibration because the magnitude of AC and DC components changes from person to person. So, there are certain patient dependent parameters like skin pigmentation, finger thickness, and presence of nail polish. It was reported that as the pigmentation darkens the performance of the pulse oximeter deteriorates. This is because of lower signal-to-noise ratio caused by increased light absorption as the pigmentation darkens. For a thick finger the optical length is more, so the attenuation is relatively high than a thin finger. It would be advantageous if the device is made independent of parameters like skin colour, intervening tissue volume etc. It would also result is better accuracy if the device works logically than by making use of calibration curves.

In order to overcome these limitations the DC value ($V_{DC}$) obtained is compared to a reference value ($V_{ref}$). The light intensity is varied till obtained DC value equals the reference value or till the difference is nullified. This is implemented as shown in Fig 2. Based on the difference the current through LED’s is changed thus resulting in a normalized signal. For instance, if the output DC value $V_{DC}$ is not equal to $V_{ref}$, will result in a current which is proportional to ($V_{ref}$-$V_{DC}$) pumped into emitters. The difference is obtained by means of subtractor, which is given to negative terminal of Howland current pump. The output current then becomes $[V_{in} - (V_{ref} - V_{DC})]/R$ as required. Thus, for a low value of $V_{DC}$, more current will be pumped into LED’s resulting in greater intensity. The AC component of PPG at any $\lambda$ can be described as

$$V_{ac\lambda} = V_{DC}([\text{Hb}]\epsilon_{Hb\lambda} + [\text{HbO}_2]\epsilon_{HbO_2\lambda})$$  \hspace{1cm} (2)

Where $[\text{Hb}]$ and $[\text{HbO}_2]$ are the concentrations of deoxy haemoglobin and oxyhaemoglobin respectively, $\epsilon_{Hb\lambda}$ and $\epsilon_{HbO_2\lambda}$ are the extinction coefficients of oxy and deoxy haemoglobin at particular wavelength $\lambda$. (2) is based on assumptions that:

i. Majority of the light absorbed is due to red blood cells, and the contribution due to other components is neglected.

ii. Absorption of light due to skin, tissue, bone constitute only to a DC value ($V_{DC}$). Introducing feedback results in $V_{DC} = V_{ref}$. Using this we can simplify (2) as

$$V_{ac\lambda} = V_{ref}([\text{Hb}]\epsilon_{Hb\lambda} + [\text{HbO}_2]\epsilon_{HbO_2\lambda})$$  \hspace{1cm} (3)

Let $Q = [\text{HbO}_2]/[\text{Hb}]$ then (3) becomes

$$V_{ac\lambda} = V_{ref}\epsilon_{Hb\lambda} + \epsilon_{HbO_2\lambda}([1-hb]/[1-Hb])([1-Hb])$$  \hspace{1cm} (4)

This can be written as

$$V_{ac\lambda} = V_{ref}\epsilon_{Hb\lambda} + \epsilon_{HbO_2\lambda}Q \hspace{1cm} ([\text{Hb}])$$  \hspace{1cm} (5)

Hence the peak to peak values of red and IR can be written as

$$V_{PB} = V_{ref}(\epsilon_1 + \epsilon_2Q) \hspace{1cm} ([\text{Hb}])$$  \hspace{1cm} (6)
\[ V_{PR} = V_{ref} (\varepsilon_3 + \varepsilon_4 Q) \text{ [Hb]} \]  

(7)

Here, \(\varepsilon_1, \varepsilon_2\) are extinction coefficients of Hb and HbO\(_2\) respectively for red. Similarly \(\varepsilon_3, \varepsilon_4\) are extinction coefficients of Hb and HbO\(_2\) respectively at wavelength of IR. The values of \(\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4\) are well known and can be obtained from absorption spectra of Hb and HbO\(_2\).

Dividing (6) by (7)

\[ \frac{V_{PR}}{V_{PIR}} = \frac{V_{ref} (\varepsilon_1 + \varepsilon_2 Q)}{\varepsilon_3 + \varepsilon_4 Q} \]  

(8)

Therefore, \(Q = \frac{V_{PIR} \varepsilon_3 - V_{PR} \varepsilon_3}{V_{PR} \varepsilon_4 - V_{PIR} \varepsilon_2} \)  

(9)

From (1) and (9) we get

\[ \text{SpO}_2 = \frac{V_{PIR} \varepsilon_3 - V_{PR} \varepsilon_3}{(V_{PIR} \varepsilon_3 - V_{PR} \varepsilon_3) - (V_{PR} \varepsilon_4 + V_{PIR} \varepsilon_2)} \times 100\% \]  

(10)

From (10), it can be seen that by incorporating feedback mechanism the calculation of SpO\(_2\) becomes patient independent. This method also makes sure that the device is calibration free. The device can be further improvised by making it independent of small changes in wavelength, by reducing the motion artefacts.

CONCLUSION

The system has been designed using minimum amount of hardware at low cost. SpO\(_2\) value is calculated using an algorithm in microcontroller and the value is displayed on GLCD. The same value is transferred to PC using Bluetooth for further reference, which is yet to be implemented.

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