A Reflectance Pulse Oximeter Design Using the MSP430F149

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Abstract-This paper will design a non-invasive optical pulse oximeter using the MSP430F149 single-chip as system microcontroller. The planned pulse oximeter consists of a sensor and a system microcontroller. The sensor is used for the pulse wave's detection, and the microcontroller is designed to analyze the pulse wave to calculate the oxygen saturation (SaO_2) and pulse rate. The results are displayed on a LCD glass or transported to PC. This paper designs a reflectance pulse oximeter sensor that includes two light emitting diodes (LEDs), one in the visible red spectrum (660nm) and the other in the infrared spectrum (890nm). The oxygen saturation is calculated by the intensity from each frequency of light after it reflects through the body tissue. The pulse oximeter uses the MSP430F149 as microcontroller, which has ultra low power capability, so the system's power consumption is very low.

Key Words-Oxygen saturation, Reflectance, Pulse oximeter, Microcontroller

I. Introduction

To obtain the oxygen saturation information easily, continuously and non-invasively is very important to some clinical management. Pulse oximeter is a basic tool to measure oxygen saturation (SaO_2), the percentage of oxygenated hemoglobin (HbO_2) in total hemoglobin. It is traditionally recommended as a standard medical device for the care of every general anesthetic, and also has been recommended as an important care tool for new born infants and patients during surgery. Pulse oximeter is a useful medical instrument for monitoring the oxygen saturation of a patient non-invasively and simultaneously.

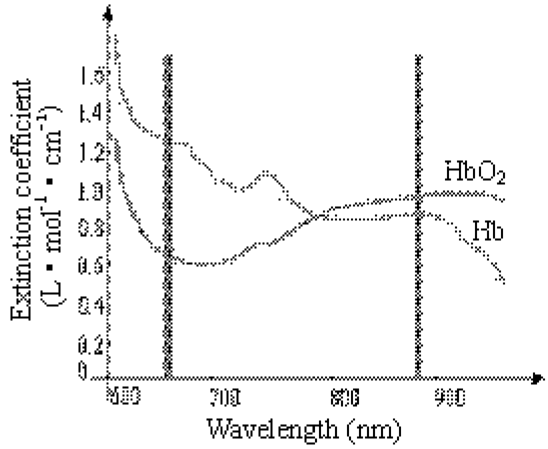

Fig.1. Light absorption characteristics

II. Theory

Oxygen saturation is defined as the ratio of the level oxygenated hemoglobin (HbO_2) over the total hemoglobin level (apart from oxygenated hemoglobin, there is deoxygenated hemoglobin in blood), that is:

$$SaO_2 = \frac{HbO_2}{Hb + HbO_2} \times 100\% \qquad (1)$$

The calculation of oxygen saturation is based upon two physical principles. First, the light absorbance of oxygenated hemoglobin is different from that of deoxygenated hemoglobin at different wavelengths, as figure 1 shows.

The second physical principle is that, when we measure the light attenuated by body tissue, we will find a direct current (DC) component and an alternating current (AC) component in the measurements. The output light at each wavelength consists of these two components. It is assumed that the DC component is the result of the absorption by the body tissue and veins, while the AC component is the result of the absorption by the arteries.

On the base of the values of the DC component and DC component of two frequencies, oxygen saturation can be finally calculated using the well known Mendelson and Kent equation which is derived based on Beer-Lambert law. In a pulse oximeter, to measure blood oxygen saturation, two different light emitting diodes are needed. Each is turned on and measured alternately. If we choose two light emitting diodes, one in the red spectrum (660nm) and the other in the infrared spectrum (890nm), the mathematical complexity of measurement can be reduced.

The formula to calculate the oxygen saturation is:

$$SaO_2 = A - B\frac{(AC/DC)_{\mathrm{Red}}}{(AC/DC)Infrared} = A - B * R \qquad (2)$$
$$(R = \frac{(AC/DC)_{\mathrm{Red}}}{(AC/DC)Infrared})$$

Where A and B are two constants, at the end of the paper, we will know how to get the values of A and B.

So far, we can find it clearly: as long as we get the values of the DC component and the AC component of the red and infrared light intensity, the blood oxygen saturation can be calculated using formula 2 easily.

III. SENSOR

In this and next sections, we will illustrate the design of the system, from the sensor to the system's microcontroller.

The function of the sensor is to get the DC component and the AC component of the red and infrared light intensity and send the pulse waves to microcontroller. And the analyzes the pulse wave to calculate the oxygen saturation and pulse rate,

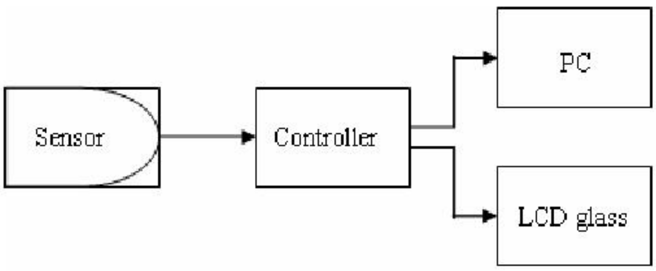

Fig.2. Block diagram of the pulse oximeter

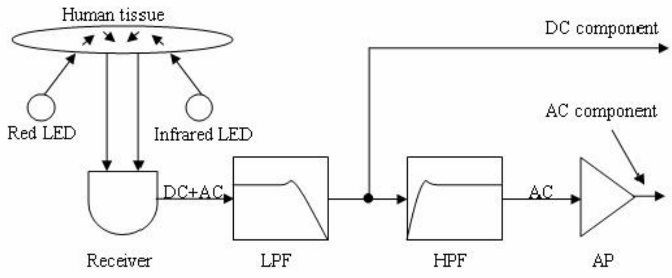

Fig.3. Sensor and its components

the results are displayed on a LCD glass or transported to PC. The figure 2 shows the whole system.

Let's begin with the sensor.

The planned sensor is consisted of a receiver, a low pass filter (LPF), a high pass filter (HPF) and an amplifier (AP). Figure 3 shows the components of the sensor and the functions of each sub-module.

As the figure 3 shows, the pulse oximeter has two LEDs to emit the red light and infrared light respectively, the receiver is used to sense the light attenuated by body tissue and convert the optical intensity signal to voltage signal. The following paragraphs will describe the components of the sensor showed in figure 3 respectively.

Figure 4 shows the design of the optical receiver. The LED is the etitex's (Japan) bio-color LED, SET660/890R, and the Si-photodiode is HAMAMATSU's (Japan) S1133-14, whose function is to sense the reflected optical intensity. When the light attenuated by body tissue is reflected to the photodiode, it will generate a very low level current. To convert this low level current signal to a significant voltage signal, a transimpedance amplifier named OPA380 (TI's product) is used. So far, we get a voltage signal wave, which includes a high level DC component and a low level AC component.

Although we already get the DC component and the AC component of the pulse wave, it is not the time to calculate the oxygen saturation. There are mainly two problems. The first is that the voltage signal has a high frequency noise, the second is

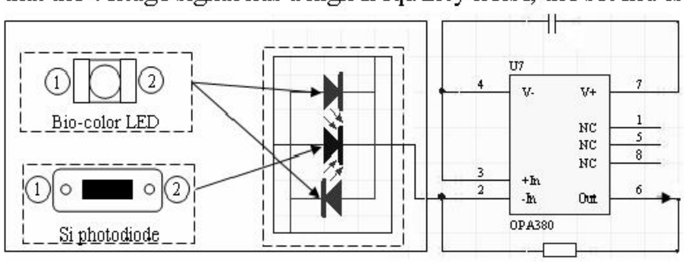

Fig.4. Receiver of the pulse oximeter

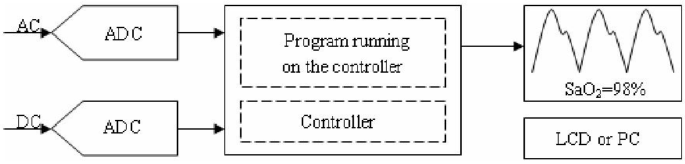

Fig.5. Controller and its function

that the AC component is too low to recognize, we can not input this very low level AC signal to ADC directly.

To solve the first problem, we design a low pass filter to filter the high frequency noise. The 3 DB cut-off frequency of this LPF is 40Hz, so the pulse wave's AC component is not be filtered. Although the level of AC component is very low, the DC component can be send to analog to digital converters (ADCs) after LPF immediately, as figure 3 shows.

In order to recognize the very low level AC component of the pulse wave, an amplifier is designed to amplify the low level AC signal to significant pulse wave. But before the AC signal is amplified, it is needed to filter the high level DC component of the signal after LPF. So, as the figure 3 shows, before the amplifier, there is a high pass filter, whose 3 DB cut-off frequency is 0.5Hz.

Up to now, we already get the DC components and the AC components of the red and infrared light intensity, so we can calculate the oxygen saturation by formula 2 theoretically. But we let the controller to do this, and to tell us the results on LCD glass.

Ⅳ. Microcontroller

In above paragraphs, we already indicated that the microcontroller is used to control the calculation of the oxygen saturation and pulse rate, and display the results on a LCD glass or transport the data to PC. The planed microcontroller is the TI's single chip MSP430F149. MSP430F149 provides a very low power consumption characteristic. Figure 5 shows the function of the microcontroller.

The sensor output the significant DC component and AC component waves, the microcontroller will process the output signals to calculate the oxygen saturation and pulse rate. But the sensor output signals are analog waves, so we should convert the waves to digital data. This is being done by two 12 bit analog to digital converters. These ADCs are integrated in the microcontroller MSP430F149.

To calculating the oxygen saturation and pulse rate as well as drawing the pulse wave on the LCD glass, some programs are developed. The program running on the microcontroller mainly does three things.

Firstly, the program sends instructions to ADCs to digitize the analog waves, and save the data to RAM.

Secondly, the program process the data in RAM further to improve the S/N ratio, and abstract the AC component and DC component of each frequency, the results are also stored in RAM.

So far, the values of DC component and AC component of each wavelength (660nm and 890nm) are stored in RAM, the program can calculate the oxygen saturation according to (2). But another problem is that the values of constants A and B are unknown. To get the values of A and B, we need a tool called oxygen saturation simulator. The oxygen saturation simulator will tell us the relationship of the SaO_2 and R in formula 2. By doing some experiments, an R to SaO_2 curve is available, as figure 6 shows.

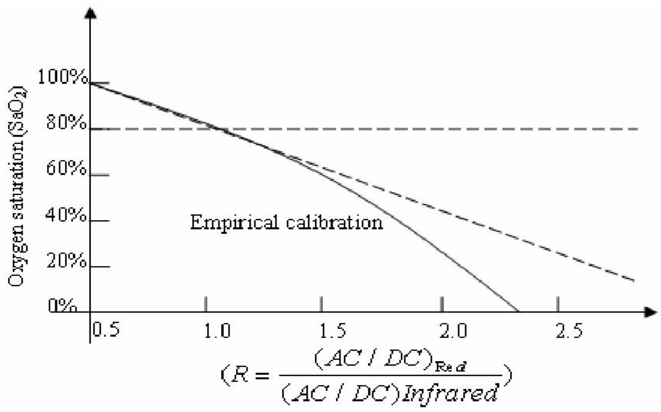

Fig.6. Empirical R to SaO_2 curve

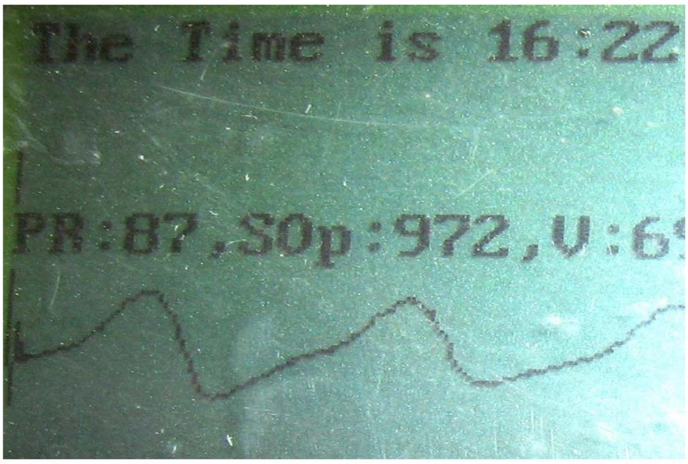

Fig.7. Pulse wave on LCD

Figure 6 shows the empirical R to SaO_2 curve. As the oxygen saturation seldom drops below 80%, a linear relationship with a slight offset can safely be assumed, which was showed in formula (2).

Now we can calculate the R using the values of the DC component and AC component of each wavelength, then, by looking up the R to SaO_2 curve, the oxygen saturation is available. We can also calculate the values of A and B by this curve, the process of the calculation of A and B is also known as calibration.

Finally, the program will send the data and results to PC for further processing, or show the results and draw the pulse wave on the LCD glass. Figure 7 shows the pulse wave on LCD glass.

V. Conclusion

The system uses the MSP430F149 as microcontroller, has mini-amount of hardware and very low power consumption. Also, lots of attempts have been made to make the entire system smaller and make the system user friendly and portable. The system has attractive features to measure the SaO_2 in the range of 78% to 100%, and the pulse rate within 30 pulses per minute to 150 pulses per minute.

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