A Non-invasive Dual-Channel Oximeter based on Near-Infrared Spectroscopy (NIRS)

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***Abstract*— Near-infrared spectroscopy (NIRS) has been used as non-invasive sensor of blood oxygen level. In this paper, we demonstrate our implementation of a compact dual-channel blood-oxygen level monitoring system based on NIRS.**

I. Introduction

In biological science, oxygen is a crucial element to lives, which is involved in many biochemical activities. Therefore, oxygen is essential to all living tissues by being involved in the respiration process and releasing energy for living cells. A plastic surgeon may want to know the oxygen content of a surgical flap in order to determine the recovery condition. It is necessary to keep the blood oxygen level high, otherwise it will cause death of tissue due to insufficient supply of energy. There are many causes for low oxygen saturation such as blockage of artery or haemorrhage, especially after surgical operation such as transplantation. However, in practice, clinical doctors screen the patient by observing the colour of the flaps and identify the flaps with low oxygen content. This process is labour intensive and time consuming, and often leads to false negative cases.

Clinical Oximeters [1] that are reported and commercially available in the market can measure one single point for its oxygen concentration. However, sometimes clinical doctors may prefer to measure two tissues at the same time. In such way, they can use one point as a reference while the other one is placed on the target monitoring tissue. The oxygen level difference signal can generate information such as blood flow and blood vessel blocking condition for further medical treatment.

In this paper, we report a non-invasive dual-channel blood oxygen meter based on near-infrared spectroscopy (NIRS) techniques. Our implementation is composed of an optical sensor module and a personal computer that are connected via Bluetooth for wireless data transmission, which can potentially be employed in tele-medicine.

II. Background

Near-Infrared spectroscopy (NIRS) has been widely applied as a non-invasive technique to measure the haemo-dynamics of tissues [2]. NIRS measures the concentration changes of oxy-haemoglobin and deoxy-haemoglobin by detecting the intensity of light at two different wavelengths. Since the absorption spectrum of oxy-haemoglobin and deoxy-haemoglobin are different, we can use this information to calculate the ratio between them, which gives us the oxygen concentration. When a light is injected vertically into a tissue, the scattering effect will eventually cause the light to reflect out of the tissue. The intensity of the near-IR light passing through a material varies by an exponential function according to Lambert-Beer law. The intensity changes are described by the following expression:

$$I_o = I_i e^{-L_t} \qquad \text{----------(1)}$$

Where I_o and I_i are the light intensity at the output and input respectively. L_t is the total loss when the light beam is propagating in the tissue. The loss in the tissue is contributed by both absorption and scattering.

$$L_t = (\mu_a + \mu_s)L + B \qquad \text{----------(2)}$$

Where μ_a and μ_s are absorption and scattering coefficients respectively, and the total amount of absorption and scattering is dependent on the path length of light propagation, L. B is a general term to include the effect of other factors which cause attenuation, for example, skin colour and thickness, and we assume that these factors are independent of wavelength. We have also assumed in our work that the variation of scattering effect in human tissue is very small for wavelength from 600nm to 800nm. Under this assumption, we can consider the difference in detected light intensity when using light source with different wavelengths as mainly due to different absorption coefficients. Hence, from (1) and (2), we have:

$$\{\alpha_{HbO_2}(\lambda)\cdot[HbO_2] + \alpha_{Hb}(\lambda)\cdot[Hb] + \mu_s\}L + B = \ln\left(\frac{I_i}{I_o}\right) \qquad \text{----------(3)}$$

where $\alpha_{HbO_2}(\lambda)$ and $\alpha_{Hb}(\lambda)$ are the absorption coefficient of oxyhaemoglobin and deoxyhaemoglobin respectively, in which they are wavelength λ dependent. There are three variables in (3), namely, concentration of oxy-haemoglobin [HbO_2], concentration of deoxy-haemoglobin [Hb], and the background noise factor B. In this paper, we are only interested in finding out the oxygen saturation level, which can be described by the following:

$$pSO_2 = \frac{[HbO_2]}{[HbO_2]+[Hb]} \qquad \text{----------(4)}$$

In order to eliminate the background noise factor, we use two photo detectors at different distances from the light source. The equation in (3) becomes:

$$\left\{\alpha_{HbO_2}(\lambda)\cdot[HbO_2]+\alpha_{Hb}(\lambda)\cdot[Hb]+\mu_s\right\}(L_1-L_2)=\ln\left(\frac{I_2}{I_1}\right)$$

---------(5)

In order to calculate the value of oxygen concentration of (4) from (5), we need at least two wavelengths. (5) thus becomes two linear simultaneous equations with two unknowns. By solving the equations we can obtain the oxygen saturation level.

III. Implementation

We have implemented the oximeter using the engineered scheme as shown in Figure 1. Two laser diodes have wavelength of 670 nm (LD1) and 780 nm (LD2) with output power of 5 mW each. Two photo-detectors (PD1 and PD2) are placed 4.5 mm and 8.5 mm away from the laser diodes. The absorption coefficients are obtained from [3]. Absorption coefficients at 670 nm are set to $0.45\times10^{-3}\,mol^{-1}cm^{-1}$ and $2.61\times10^{-3}\,mol^{-1}cm^{-1}$ for oxyhaemoglobin and deoxy-haemoglobin respectively. For the 780 nm laser, the absorption coefficients are set to $0.542\times10^{-3}\,mol^{-1}cm^{-1}$ and $0.782\times10^{-3}\,mol^{-1}cm^{-1}$ for oxyhaemoglobin and deoxy-haemoglobin respectively. The scattering coefficient μ_s for all the cases is set to $0.10cm^{-1}$.

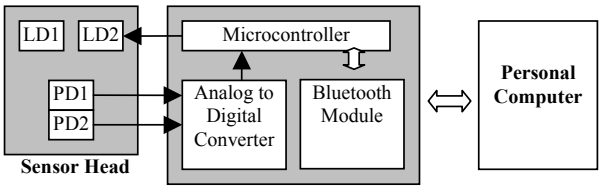

Figure 1 Schematic of the optical sensor head design

Figure 2 - Photo of the Oximeter prototype

In Figure 1, a microcontroller chip is used to control the on-off status of the laser diodes labelled as LD1 and LD2. The outputs from the photo-detectors PD1 and PD2 are connected to the analogue to digital conversion port of the microcontroller. The microcontroller turns on one laser at one time. The captured readings from the photo-detectors are sent to a personal computer (PC) by Bluetooth wirelessly and then analysed using our predefined model in Section II. The PC is responsible to display the data and send the alarm signal to the sensor module. A rechargeable battery is included in the sensor module.

Figure 2 shows the photo of the Oximeter prototype. The sensor head size is about 20mm x 35mm. Two sensor modules are made and they can both be wirelessly connected to the same PC via Bluetooth at the same time. The PC can be programmed to generate alarm whenever the blood oxygen level is under a predefined threshold or the difference between two channels is larger than an acceptable pre-set value.

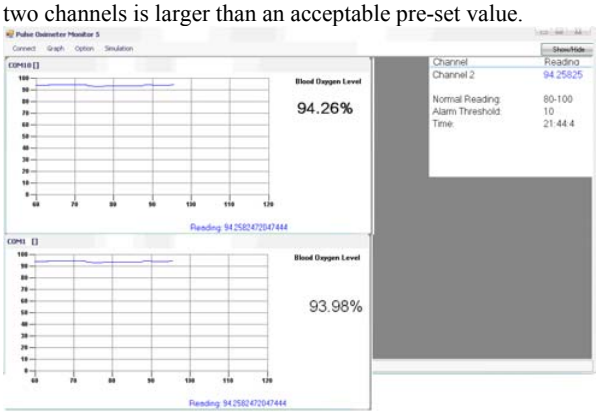

Figure 3 - User Interface on PC

Figure 3 shows the user interface on the PC. The captured data is analysed and displayed. The measured oxygen saturation value of an adult forearm is within the range of 85% to 95%.

IV. Conclusions

We have implemented a non-invasive dual-channel oxygen meter using near-infrared spectroscopy (NIRS). We believe this is the first demonstration of such a miniaturized dual-channel Oximeter for blood-oxygen level monitoring via NIRS with wireless connection. Its compact size makes it a very good candidate for clinical monitoring as well as home-care medical applications. The PC may be further replaced by PDA (Personal Digital Assistant) or a Tablet PC which are much smaller in size.

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