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Implementation of a Wireless Pulse Oximeter Based on Wrist Band Sensor

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***Abstract*—In order to develop a wrist band pulse oximeter, the detected light intensities and effective transmission depth of reflectance oximetry are investigated by analyzing the light propagation through tissue. A reflectance probe is fabricated based on the analytical results. An oxygen saturation measurement system is also implemented and some preliminary experiments are conducted. The experimental results have confirmed the feasibility of this wrist-band oximeter. Home healthcare can be ensured by transmitting the realtime measurements through wireless technology to the community monitoring system.**

Keywords-* *Wrist-band sensor; Oxygen saturation; Remote healthcare

I. INTRODUCTION

Non-invasive pulse oximetry has been widely used in clinical care for critical ill patient, monitor of patient during the anesthesia in operations, research of breath state while sleeping, etc. It's a safe, reliable, real time and continuous measurement method. Nowadays transmittance oximetry has been fully developed and there're many mature products which are widely and frequently used in hospitals. However, a transmittance pulse oximeter is reliable and practical only in case the patient is hospitalized or lying steadily. Besides, transmittance measurements sometimes cause discomfort, pain or injury because its sensor lightly presses a finger or ear lobe and occasionally blocks the blood flow. A reflectance oximeter which increases the flexibility of installation can avoid such problems and meet the needs of modern home healthcare, whereas the research of reflectance oximeters is still in a shortage relative to the transmittance type and there are few complete solutions for reflectance oximetry[1][2].

In this study, the detected light intensities and effective transmission depth of reflectance oximetry are investigated by analyzing light propagation through tissue using the photon diffusion equation. We fabricated a reflectance probe based on the analytical results, implemented an oxygen saturation measurement system and conducted some preliminary experiments, whose results have comfirmed the feasibility of our oximeter. We also implemented a RF transmitting module to found a communication between the measurement system and community care center to ensure home monitor of oxygen saturation, which is mainly used in night care of patients with sleep apnea syndrome [3].

II. THE PRINCIPLE OF RELECTANCE OXIMETRY BASED ON DIFFUSION PROPAGATION THEORY

Human tissue is a strongly scattering media, in which the movement of light is random. In transmittance oximetry, the light detector mainly receives the forward scattered light; while in reflectance oximetry, the light source and the detector are both placed on the same side of the measurement site, the detector mainly receives scattered light after a parabolic path in tissue, as shown in figure 1.

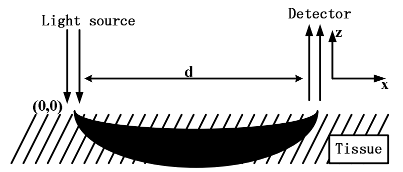

Figure 1. Boundary of the parabolic region for photon path distribution

A. Detected light intensity

For most human tissue, the scattering coefficient is much greater than the absorption coefficient. Therefore, when the scattering length of tissue is much smaller than its geometric dimensions, the photon will experience repeatedly scattering before it's absorbed or escaping outside the tissue boundary. In this case, the photon migration in biological tissue can be considered as a diffusion process. Light propagation in homogeneous biological tissue can be described by photon diffusion equation [4]:

$$\frac{1}{c}\frac{\partial}{\partial t}\phi(r,t) - D\nabla^2\phi(r,t) + \mu_a\phi(r,t) = S(r,t) \qquad (1)$$

Where $\phi(r,t)$ is the fluence rate at the position r in the tissue, which means the effective photon density at the position r at time t. D represents diffusion coefficient, μ_a is absorption coefficient and $S(r,t)$ represents the light source.

The diffusion coefficient D for photon migration is:

$$D = \frac{1}{3\{\mu_a + (1-g)\mu_s\}} \quad (2)$$

Thus the density of the photon leaving the tissue is given by the flux of the fluence and the detected light intensity is:

$$\phi(\rho,t) = (4\pi Dc)^{-3/2} z_0 t^{-5/2} \exp(-\mu_a ct)\exp(-\frac{d^2+z_0^2}{4Dct}) \quad (3)$$

Where z_0 is $[(1-g)\mu_s]^{-1}$, d is the source-detector separation.

When time is long enough, the change rate of reflected light intensity is as below:

$$\lim_{t\to\infty} \frac{\partial}{\partial t} \ln \phi(\rho,t) = -\mu_a c \quad (4)$$

Therefore the change rate of reflected light intensity is proportional to tissue's absorption coefficient [4].

In the near infrared region, the absorption caused by such substance as water, cytopigment, etc. is much smaller than that caused by oxygenated hemoglobin (HbO2) and reduced hemoglobin (Hb), and the light absorbance of HbO2 is different from that of Hb at two different wavelengths. Therefore when illuminating the tissue containing an arterial bed with light of different wavelengths, we can deduce the oxygen saturation from the ratio of change rates of reflected light intensity in these two wavelengths.

Note the change rate of reflectance light intensity W, the blood oxygen saturation can be expressed as:

$$SpO_2 = A - B \cdot \frac{W_{\lambda 1}}{W_{\lambda 2}} \quad (5)$$

The light attenuated by body tissue consists of a direct current (DC) component and an alternating current (AC) component. 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 fluctuating volume of arterial blood. The change rate of reflectance light intensity can be expressed as: $W = I_{AC}/I_{DC}$, accordingly the formula for determining oxygen saturation can be obtained :

$$SpO_2 = A - B \cdot \frac{I_{AC}^{\lambda 1}/I_{DC}^{\lambda 1}}{I_{AC}^{\lambda 2}/I_{DC}^{\lambda 2}} \quad (6)$$

B. Effective transmission depth

In order to measure oxygen saturation, it is important to know whether or not the light reaches the arteries and the pulse wave is detected. The distribution function of photon path in tissue is [5]:

$$P(x,y,z) = \frac{z^2 \exp(-k\{(x^2+y^2+z^2)^{1/2} + [(d-x)^2+y^2+z^2]^{1/2}\})}{(x^2+y^2+z^2)^{3/2}[(d-x)^2+y^2+z^2]^{3/2}} * [k(x^2+y^2+z^2)^{1/2}+1]\{[(d-x)^2+y^2+z^2]^{1/2}+1\} \quad (7)$$

As is shown in figure 1, the photon path in tissue is parabolic in the x-z cross section. Under conditions of weak absorption (kd<<1), when coordinate is (x,0,0) the z position z0 (x) of the cambered region is:

$$z_0(x) \approx \sqrt{\frac{1}{8}\left[\sqrt{\left[x^2+(d-x)^2\right]^2 + 32x^2(d-x)^2} - x^2 - (d-x)^2\right]} \quad (8)$$

The maximum depth the incident light reaches is called effective transmission depth. z_0 reaches the maximum when x=d/2;

$$z_0^{max} \approx \sqrt{2}d/4 \quad (9)$$

This shows that the effective transmission depth depends on the source-detector separation d. So choose a suitable distance between the light source and detector can ensure the effective detection of blood oxygen saturation.

III. SYSTEM DESIGN AND IMPLEMENTATION

A. System design

The system consists of wristband sensor, signal acquisition and processing module, wireless transmission module, power module, display module, etc. Figure 2 shows the system block diagram.

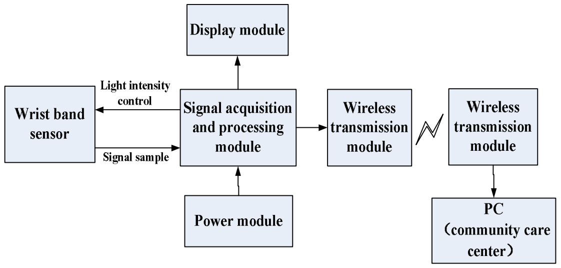

Figure 2. System block diagram

B. Sensor

A wrist located reflectance sensor is used to sample the pulse wave signal. It has functions of optical source control, signal conversion and signal amplification. It's composed of light source, light detector, and a wrist band which is used for mounting the sensor.

For reflectance oximetry, the ratio of absorption coefficient in the wavelength of 660nm and 900nm is the most sensitive to the change in oxygen saturation. To avoid the difference of transmission path caused by the distance between two separated light sources, the system employs dual-wavelength light-emitting diode as the light source, with the peak emission wavelength of 940nm and 660nm.

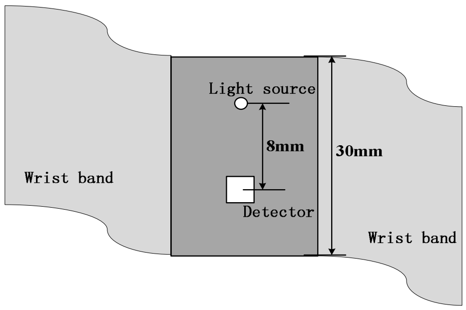

Figure 3. Wristband sensor

By the formula (3) and (9), both the detected light intensity and effective transmission depth are affected by the source-detector separation. To ensure sufficient detected light intensity and transmission depth, the optimum source-detector separation was chose as 8mm based on several experiments. The wristband sensor design is shown in Figure 3. To get the best measurement effect, the wrist band mounts the sensor on the inner wrist right above the arterial vessel.

C. *Signal sampling and processing*

To meet the design requirements of miniaturization, portable and low power consumption, the system employs MSP430 microcontroller as the core of hardware control, data processing and transmission.

The internal 12-bit DAC0 in the MCU periodically send two pulses to light source drive module, making light emitting diode emit red and infrared light alternatively to obtain optical modulation. When the pulse beats, the volume of blood flow through the wrist artery changes, the detected red and infrared light intensity changed consequently. The ADC sampled the output signal of the light detector so as to get the modulated photoplethysmography signal.

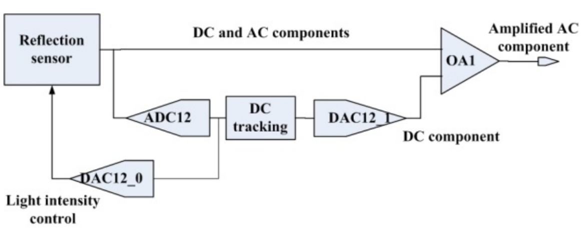

Figure 4. Signal procesing diagram

The AC component of this signal is effectively extracted and amplified through differential amplification performed by the built-in operational amplifier OA1 of the microcontroller. Figure 4 shows the processing procedure of pulse signal.

The initial pulse wave signal extracted at this stage comprises electromagnetic interference and power supply noise; therefore, it's necessary to eliminate ambient noises in 50Hz and above, considering the fundamental frequency of the pulse wave is about 1Hz[6]. A symmetric FIR filter as is shown in formula (10) is implemented for removing the noise, with cutoff frequency of 6Hz and -50dB attenuation in 50 Hz and above. Where x[n] and y[n] represents the input and output signal respectively, while N represents the length of the FIR filter. h[n] is the FIR filter coefficients.

$$y[n] = \sum_{k=0}^{N} h[k]x[n-k]$$
$$h[n] = h[N-n] \qquad (10)$$

Figure 5 shows the initial pulse wave signal extracted by the built-in amplifier and effective pulse wave signal after filtering. As can be seen from the figure, the system efficiently detected the human pulse wave signal， indicating that the incident light can visit the arterial vessel.

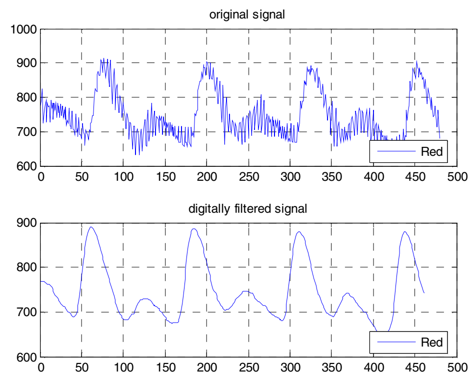

Figure 5. Original signal(upper) and filtered signal(lower) of pulse wave

The heart rate is measured by calculating the cycle of pulse wave signal, and the oxygen saturation is deduced by computing the ratio of the light intensity change rates under two different wavelengths. The real time measurement results and pulse wave are displayed on an OLED continuously

D. *Wireless data transmission*

The wireless transmission module founds a communication between measurement system and community care system, transfers the measurement results to a PC. Therefore, a number of users can be centralized monitored by creating a small wireless network.

The wireless transmitting module consists of a transceiver CC2500, a chip antenna, etc. CC2500 is a single chip transceiver designed for very low power wireless applications and intended for the ISM frequency band at 2.4 GHz. Wireless receiving module integrates a MSP430 MCU, CC2500 RF transceiver and a USB interface. It can be directly connected to the PC of community care center.

Wireless transmitting module communicates data with measurement system through the SPI interface and sends measurement results to the receiving module. Wireless receiving module transfers the received data to the PC of community care system via USB interface. RF chip CC2500 keeps control of RF module and IEEE 802.15.4 protocol to regulate the wireless transmission of measurement data.

Several oximeters can easily set up a star wireless network [7]. Transmission distance can reach 100m in an open space, relay stations are needed while transferring data for farther distance or through walls.

IV. Experimental Results

To test the reliability of this system, an apnea experiments is conducted; five healthy people took part in this experiment. We recorded the values of R at time intervals during the slowly recovery process after several seconds of breath holding, and drew the value changes in line graphs as shown in Figure 6.

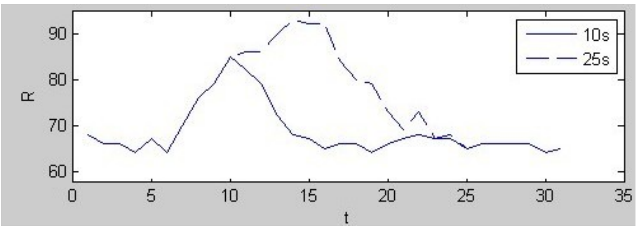

Figure 6. Change map of the value of R after breath holding for 10s and 25s

About 6s after the apnea, R values began to rise to a peak, which means oxygen saturation began to decrease. It can be seen from the comparison of these two graph that for the longer time of breath holding, the increasing amplitude of R is larger, that is the decreasing extend of oxygen saturation is larger, and the recovery time is longer as well.

The experimental results indicate that this system can effectively detect the change of oxygen saturation

V. Conclusion

This paper describes the system design of a wristband pulse oximer and completes the prototype fabrication. This oximeter can obtain oxygen saturation and heart rate information continuously and non-invasively through a wearable reflection sensor placed on the inner wrist; its facility makes it quite suitable for daily home care. From the waveform and measurement results it can be seen that the system can achieve the wrist pulse signal acquisition and noise filtering. The preliminary experiments have confirmed the reliability of the measurement results. The wireless transmission module transfers real time measurement data to community care center, providing the basis for community centralized care and remote monitoring. This wrist band pulse oximeter offers an effective means of home monitoring oxygen saturation, which has a broad application scope and aspects

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