Design and implementation of a reflection pulse oximeter in tele-monitoring system

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***Abstract*—Pulse oxygen saturation is an important physiological parameter for monitoring oxygen content and respiratory function. It is very inconvenient that the pulse oximeter in the hospital use transmission probe and the data measurement have to be done in close range. Therefore, this paper designed a reflection pulse oximeter in tele-monitoring system. Firstly, a reflection oximeter which is based on reflection sensor DCM03 and microcontroller MSP430 is designed. Subsequently, Zigbee wireless module is integrated on the circuit board to realize remote measurement. Finally, the second derivative of photoplethysmography waveform derived from photoplethysmography signal is analyzed. Some experiments are conducted in the end and the method proposed maybe help confirming the relationship between SDPPG (second derivative of photoplethysmography) and human tired or diseases.**

Keywords—Reflection; Zigbee; tele-monitoring system; SDPPG; heart rate

I. INTRODUCTION

Non-invasive pulse oximetry is a safe, reliable, real time and continuous measurement method and has been widely used in clinical care. Nowadays transmittance oximetry has been fully developed and there're many mature products which are widely used in hospitals [1]. However, a transmittance pulse oximeter practical only in case the patient is in hospital or lying steadily. Besides, transmittance measurements sometimes cause uncomfortable because its sensor presses a finger or ear lobe. The reflection pulse oximeter can increase the flexibility and avoid the problems above, whereas the research of reflectance oximeter is still immaturity [2]. At present, the PPG monitoring system used in the hospital receive the PPG signal through wire and the data can't be observed by the people who are not in this region, which is extremely inconvenience. However the system designed by us solves the problems above. In addition, the reflection oximeter we design is more convenience than the transmittance one because we need to contact to the sensor only rather than put the finger or ear lobe in the transmission oxygen probe

In this paper, we design a reflection pulse oximeter using sensor DCM03 made by APMKorea and microcontroller MSP430FG43x made by TI. In order to meet the needs of modern community healthcare, we design a reflection pulse oxygen saturation tele-monitoring system using Zigbee wireless module and GPRS network system [3] [4]. We also accomplish some experiments used the reflection oximeter we designed to prove whether is there relationship between SDPPG and human tired or diseases.

The paper is organized as follows. The system architecture is introduced in Section II. The design of the reflection oximeter is described in Section III. Simulation results and data analyses are presented in Section IV. Finally, the conclusions are summarized in Section V.

II. SYSTEM ARCHITECTURE

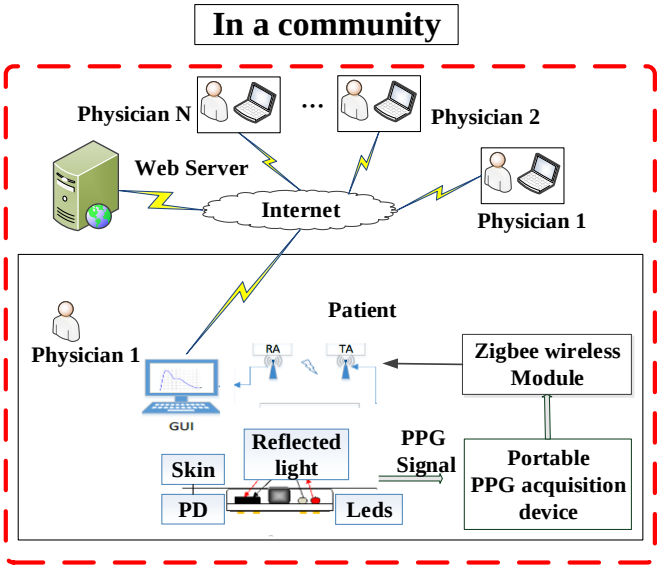

Fig. 1 Diagram of the system architecture

The diagram of the architecture of the reflection pulse oxygen saturation tele-monitoring system is showed in Fig.1. In this system, the PPG (photoplethysmography) signals are obtained by reflection sensor and processed by the portable PPG acquisition device. After the PPG signals are acquired by the device, if people and physicians are in a community, the Zigbee wireless module integrated on the portable device will transmit the PPG signal and the value of the SpO2 and the PR which are processed and calculated by the device to the display interface on the computer in real time. At the same time, the display interface upload the data to the web server, so that the physicians out of the community can observe the data. The physicians and the people themselves can observe

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the real-time physiological parameters, medical records and analysis of significant medical event.

III. REFLECTION PULSE OXIMETER

A. Theory

The oxygen saturation is obtained by the formula (1), the Hb is short for deoxygenated hemoglobin and the HbO_2 is short for oxygenated hemoglobin.

$$SpO_2 = \frac{HbO_2}{Hb + HbO_2} \times 100\% \tag{1}$$

As we all know, we find AC (alternating current) component and DC (direct current) component when we measure the light intensity after they reflected from the skin. SpO_2 can be calculated on the base of the values of the two components by the Mendelson and Kent equation. Two different light emitting diodes must be used in the sensor and each is turned on alternately. When we choose the light emitting diodes whose wave lengths are 660 nm (red) and 890 nm (infrared), we can obtain a more simple formula (2) to calculate the SpO_2.

$$SpO_2 = a - b \times R$$
$$(R = \frac{(AC/DC)_{red}}{(AC/DC)_{\inf rared}}) \tag{2}$$

Therefore, we can obtain the SpO_2 easily so long as we obtain the values of the AC component and DC component of the R (red) and IR (infrared) light intensity after they reflected from the skin.

B. Device design

One of the most important components is the reflective oximeter sensor. We choose the sensor DCM03 produced by APMKorea, and it's a sensor integrated built in LEDs and PD (photodetector) together with optimized properly against some trade-off to get proper parameters. Thus the selection of a particular separation distance involves a trade-off. We can achieve larger plethysmograms by placing the PD farther apart from the LEDs but you need higher LED driving currents to overcome absorption due to increased optical path length. Most of the light being transmitted (reflected) from the LEDs must not reach the photodiode unless it has passed through tissue containing arterial blood. To limit the light reaching the PD to that which has limit to travel through tissue containing arterial blood, DCM03 has black isolator to minimize such cross talk between LEDs and PD.

The PD in the sensor is the main input device of the pulse oximeter. After sensing the intensity of light emitted by each LED after the light passes through the tissue, the PD produces a current which is linearly proportional to the intensity of incident light. This current is then converted to a voltage which is passed on to the pulse oximeter for processing.

Now we get the large DC component and the AC component of the pulse wave, while the DC component is caused by the lesser oxygen bearing parts of the body tissue and scattered light and the AC component is made up of the light modulation by the oxygen bearing parts such as the arteries and the noise from ambient light at 50/60 Hz. But we can't calculate the oxygen saturation now because of the presence of noise. So we design a LPF (low pass filter) to filter the high frequency noise such as the power frequency disturbance before we pass the signal that come from PD on to the microcontroller MSP430FG43x, as Fig. 2 shows. The AC component is not be filtered because the 3DB cutoff frequency of the LPF filter we designed is 40Hz, while the frequency of the valuable signal is lower than 40Hz.

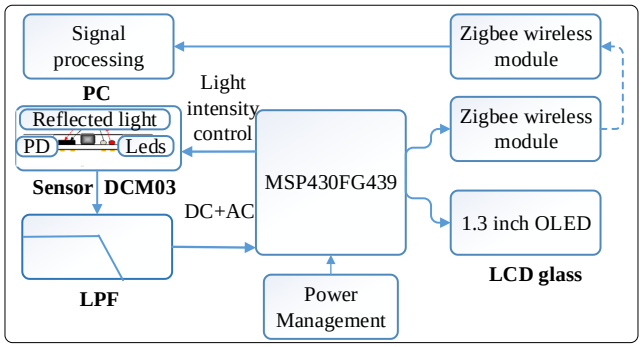

Fig. 2 Diagram of reflection oximeter

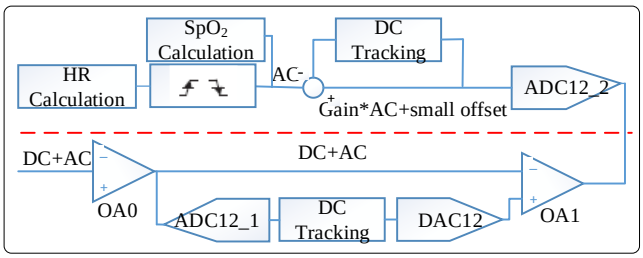

Fig. 3 Diagram of signal processing

The components of the pulse wave are very low especially the AC component, so when the DC and AC components are transmitted to the microcontroller MSP430, two amplifiers OA0 and OA1 are used to amplify the components. As Fig. 3 shows, the amplification components of the OA0 amplifier output include DC and AC components. So, before the second stage amplifying, the DC tracking filter extracts the DC component of the signal. Then the DC component is used as an offset input to OA1. So, only the AC portion of the incoming signal is amplified.

The output signals of sensor are analog waves, so we should convert the waves to digital data. As the top portion of the Fig. 3 shows, the output of the amplifier OA1 is sampled by the ADC12_2 at 1000sps, each signal is sampled at 500sps because there are two LEDs including red and infrared. The output of the ADC12_2 include AC component amplified and small offset, but we can't implement a high pass filter whose cutoff frequency is too low in order to remove the small offset, so a IIR filter is applied to track the DC level. The small offset is then subtracted from the output of the ADC12_2. At this stage we get the signal resembles the pulsing of the heart beat

through the arteries, so the SpO_2 and the HR (heart rate) can be calculated in the microcontroller now.

All of the works showed above can be done only needing a microcontroller MSP430FG43x apart from four transistors that used to control the light intensity of the LEDs and a few passive components. OAs and ADCs integrated in the MSP430 is one important reason why we choose MSP430 as the main microcontroller. Another important reason is that it provides a very low power consumption characteristic, while this is important for the portable acquisition device.

There is one important problem to be solved now. It is getting the values of a and b in formula (2) to calculate the values of the SpO_2. To get the values, a tool named oxygen saturation simulator is needed. It will tell us the relationship of the SpO_2 and R. By doing a few experiments, a curve about SpO_2 and R is available. We can calculate the value of a and b by this curve, this process is well known as the experimental calibration.

Fig. 4 Picture of the portable reflection oximeter

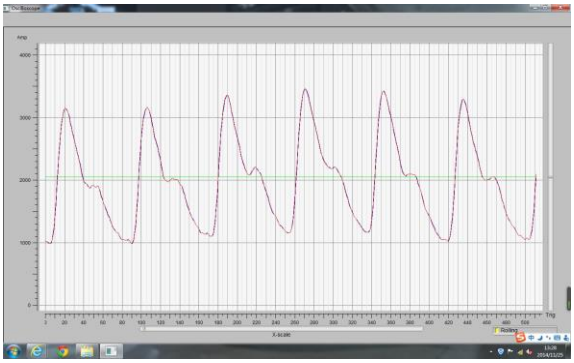

Fig. 5 The PPG signal on the display interface

The HR is measured by calculating the cycle of pulse wave signal. Finally, the MSP430 is used to calculate the SpO_2 and HR, and display the values of them on the OLED or transport them and the PPG waves to the PC via Zigbee wireless module continuously. Fig. 4 shows the picture of the portable reflection pulse oxygen saturation acquisition device. The number in the top of the OLED is the value of SpO_2 and the one in the bottom of the OLED is the value of HR or PR. The Zigbee wireless module was integrated on the circuit board in the box to transmit data. As is shown in the Fig. 5, the pulse waves on the display interface we get via the device we design is very smoothness. All of these improve that our design of the reflection pulse oxygen saturation acquisition device is applicable.

IV. Data Analysis of the PPG Waves

As we all know, the PPG is a noninvasive method to measure blood volume change. At the end of the paper, we prove that the SDPPG derived from the PPG can be used to monitor the arterial condition, while the data of the PPG signals were recorded from the portable reflection pulse oximeter we designed.

Five healthy volunteers take part in this analysis. The data of SDPPG were analyzed off-line using MATLAB. We extract the data of pulse waveforms through software, and handle the data using MATLAB. The PPG signal of volunteer A1 are shown in Fig. 6, while the FDPPG (first derivative of PPG) was shown in Fig. 7.

The SDPPG waveform for volunteer A1 is showed in Fig. 8. It consists of the initial positive wave (a wave), early negative wave (b wave), re-uplosping wave (c wave), late downsloping wave (d wave), and diastolic positive wave (e wave) and the shift from the baseline to the peak of each wave is taken as the value for each wave. The SDPPG wave pattern is determined by the proportions of the b, c, d and e waves to the a wave [5].

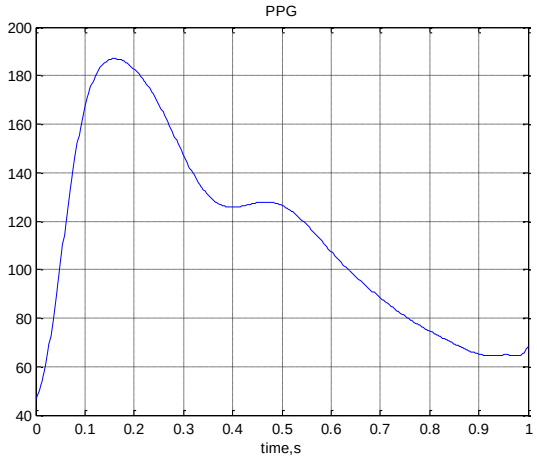

Fig. 6 PPG waveform of normalized finger for subject A1

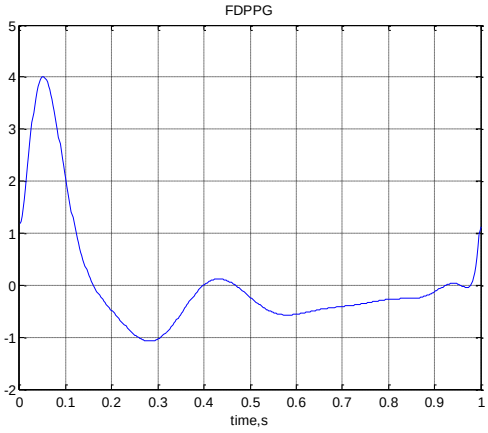

Fig. 7 First derivative signal of PPG

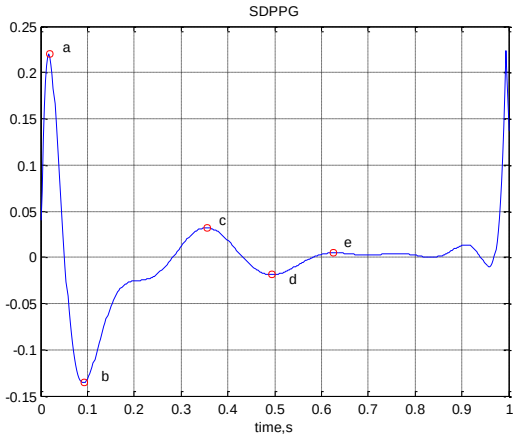

Fig. 8 SDPPG waveform for subject A1

TABLE I. Summary of data for study sample

Subject		SDPPG-AI (volunteers')	SDPPG-AI (not real data)
No.	*Age(years)*		
A1	23	-0.79±0.03	-0.71±0.11
A2	24	-0.81±0.15	-0.72±0.13
A3	25	-0.84±0.18	-0.75±0.07
A4	25	-0.86±0.22	-0.78±0.20
A5	24	-0.73±0.16	-0.69±0.14

SDPPG aging index (SDPPG-AI) can be calculated by the equation (3).

$$\text{SDPPG-AI}=(b\text{-}c\text{-}d\text{-}e)/a \tag{3}$$

The values of a, b, c, d and e were got from the MATLAB. As shown in Fig. 8, the ordinate value of point a is the ordinate value of the first positive extreme point in one cycle, while the ordinate value of point b is the ordinate value of the first negative extreme point in the same circle. The rest c, d and e can be done in the same manner. Then we calculate the values of the SDPPG-AI and do some analysis. We estimate the human tired and some diseases may be related to the SDPPG-AI, and now we are conducting some experiments, but because the number of the samples is too small, we don't show the data analysis here. But we are sure of that we can employ the data obtained from the reflection oximeter we design to do some analysis about human tired and some diseases.

Fig. 9 shows the comparison of SDPPG-AI for healthy volunteers and a set of unreal data. The mean and standard deviation of SDPPG-AI are displayed in Table 1. The left part of table 1 was obtained by the device we designed, while the data of the right part were comparative data that we set. We just want to declare that we can analyze the relationship between SDPPG-AI obtained from the reflection oximeter we designed and tired or some diseases through the data comparison. We believe that the comparison about SDPPG-AI obtained from the reflection oximeter may be a useful method to evaluate the human tired and diseases in the future.

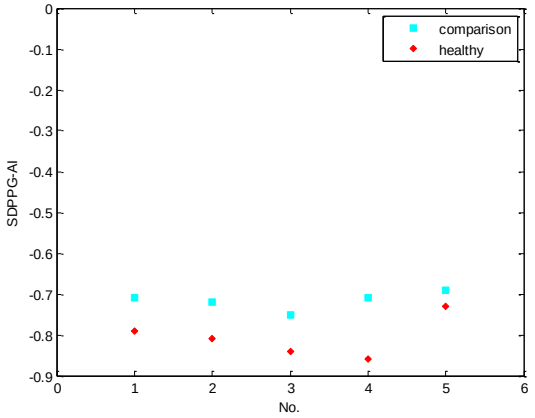

Fig. 9 SDPPG-AI for each volunteer

CONCLUTION

This paper describes the Design and implementation of a reflection pulse oximeter in tele-monitoring system. The reflection oximeter we design can obtain oxygen saturation and heart rate information continuously, non-invasively and real-time through a reflection sensor DCM03. The system is a tele-monitoring system using Zigbee wireless module and GPRS network. Therefore, it is suitable for real time and remote monitoring. In the end of the paper, we thought that there may be some relationship between SDPPG-AI and some diseases and human tired. But we have a lot of work to do to prove it. We believe that detecting the SDPPG waveform may be a useful method to monitor human health in the future.

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