Research and Design of a Wearable Oxygen Saturation Acquisition Device

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Abstract

Due to the lack of timely acquisition of physiological parameters in the fire rescue operation and long-time aerobic exercise, many people lost their life. For the reason, a wearable blood oxygen saturation acquisition system based on glove was designed. The device used reflection probe to acquire photoplethysmography signal and STM32L151 microprocessor to process data, and used the dual-tree complex wavelet transform(DTCWT) and morphological filtering algorithm to remove the noise and baseline drift, and finally sent the data to mobile phone app through Bluetooth. By the test, the device is small and easy to wear, and has low power consumption and anti-motion-interference ability, and compared with standard monitor, the error of blood oxygen saturation is within 3.1%.

Keywords

Wearable, blood oxygen saturation, DTCWT, morphological filtering.

1. Introduction

As an important physiological parameter, blood oxygen saturation indirectly reflects the metabolic state of human cells. According to statistics, nearly 30 firefighters are sacrificed and more than 300 people are injured and disabled every year in our country, also in the field of sports, there are nearly 450 people who have died of sudden cardiac death every year. Duo to the high pressure fire rescue and overworked aerobic exercise, body often remains in an anoxic state, if it last long, life will be threatened. for the sake of life safety, it is important for real-time detection of oxygen saturation in fire fighting and sports field.

At present, the oxygen saturation detection device on the market is mainly used in hospital and family monitoring, it is useful in the static environment, but limited in the process of fire rescue and movement. Considering the portability, real-time, low power consumption, and anti-interference ability, this paper designs a glove type wearable body signs acquisition device, which collects blood oxygen and pulse rate, then sends them to mobile phone, and last uploading to the cloud platform by phone app.

2. System Design

The device uses a transmission type of blood oxygen probe to collect pulse wave signal, and the acquisition site is fingertip. The micro circuit module is built in the back of the glove, the dual light source LED and photoelectric converter are embedded in rubber material which is fixed at fingertip. System design block diagram is shown in Figure 1.

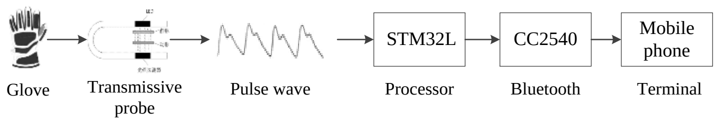

Fig. 1 The diagram of system design

3. Hardware Design

The hardware part mainly includes the MCU processing module, power management module, pulse wave signal acquisition module, and Bluetooth module. The hardware block diagram is shown in Figure 2.

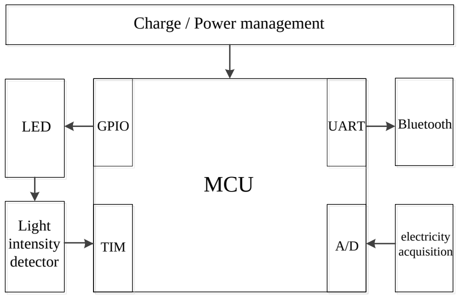

Fig. 2 The diagram of hardware design

3.1 MCU Control Circuit

This design selects the low power microprocessor STM32L151CBT6, which uses ST's own 130nm ultra-low leakage technology, and has advanced ultra low power mode, and special security performance, and makes a good balance between high performance and ultra-low power consumption. The control circuit is shown in Figure 3.

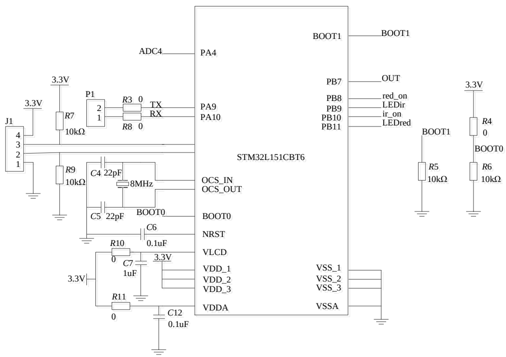

Fig. 3 The MCU control circuit

As shown in Figure 3, the MCU system clock uses HSI and works at 16Mhz frequency. Pins of red_on, ir_on, LEDir, and LEDred are connected with the pulse wave signal acquisition circuit, which controls the red and infrared light alternately. Pin of OUT is used to capture the original pulse wave signals sent back by light intensity detector. Pin of TX are responsible for transferring the processed data to the Bluetooth module.

3.2 Pulse Wave Signal Acquisition Circuit

The pulse wave acquisition circuit includes two parts: one is the drive circuit composed of transistors and resistors, the other is the signal acquisition circuit composed of diodes and the light intensity detector. As shown in Figure 4.

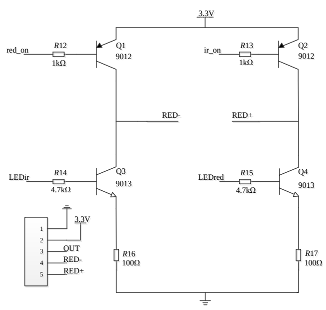

Fig. 4 The pulse wave signal acquisition circuit

There is a different absorbance between Oxyhemoglobin and Deoxyhemoglobin, especially at wavelength 660nm and 940nm[1], so using a device encapsulated by two LEDs which can emit both red light (wavelength 660nm) and infrared light (wavelength 940nm). The light intensity detector can convert the received light into the digital signal and send it to MCU by output pin.

4. Software Design

The software design mainly includes the acquisition, transmission, processing of pulse wave signals, and the calculation of blood oxygen saturation and pulse rate. The process is shown in Figure 5.

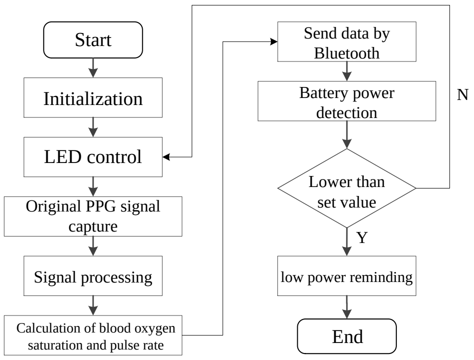

Fig. 5 Flow chart of software

First, the program starts the internal crystal oscillator, and initializes each module, including I/O, USART, ADC, TIMER, DMA. Then, lighting red and infrared light alternately, when the LED is on, the TIM4_CH2 channel of the MCU begins to capture the data. The collection period of two data is 12ms, but in a cycle each of the red and infrared light continue to light 2ms, the remaining time is off, to reduce power consumption. When 2000 sets of data are collected, the processing begins. At last, calculating the oxygen saturation and pulse rate and sending to the mobile phone.

5. Data Processing and Calculation

5.1 Morphological Filtering

In normal conditions, the center line of the signal is a straight line, but actual it often swings up and down with time, which is called the baseline drift. The essence of the baseline drift is the instability of the signal DC component, it is mainly caused by the breathing movement of the human body and the contact displacement between the detector and skin[2]. Baseline drift can be eliminated by morphological filtering.

Morphological filtering is a nonlinear filtering technique, the core of the algorithm is to filter the characteristic waveform of the pulse wave signal through the operation of corrosion, expansion, morphological opening and morphological closing[3], and Subtract the baseline drift signal from the original signal, so as to get the signal with stable DC component.

Corrosion is a process that causes the boundary to shrink inward, and the expansion makes the boundary expand outward. The operations of corrosion and expansion are as follows:

$$(f \odot g) = \min_{j=0,\dots,m-1} [f(i+j) - g(j)], (i = 0,\dots,n-m) \tag{1}$$

$$(f \oplus g) = \max_{j=0,\dots,m-1} [f(i-j) + g(j)], (i = m-1,\dots,n-1) \tag{2}$$

The signal corrodes first and then expands, it is opening operation.

$$(f \circ g) = (f \odot g) \oplus g \tag{3}$$

The signal expands first and then corrodes, it is closed operation.

$$(f \bullet g) = (f \oplus g) \odot g \tag{4}$$

The opening operation can remove burrs and isolated points, and the closed operation can fill the hole and make up the gap. Its process is shown in Figure 6.

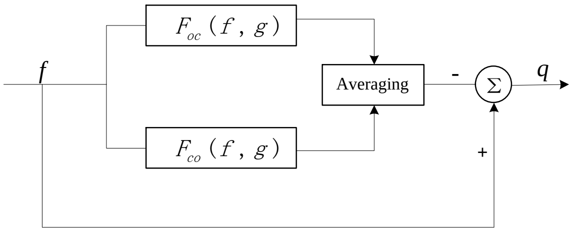

Fig. 6 The flow chart of morphological filtering

5.2 The Dual-tree Complex Wavelet Transform

The dual-tree complex wavelet transform originally proposed by Kingsbury[4], and improved by Selesnick and others[5].

DTCWT is based on discrete wavelet transform, but it overcomes its defects of translation sensitivity and frequency aliasing[6]. Its structure is as shown in Figure 7.

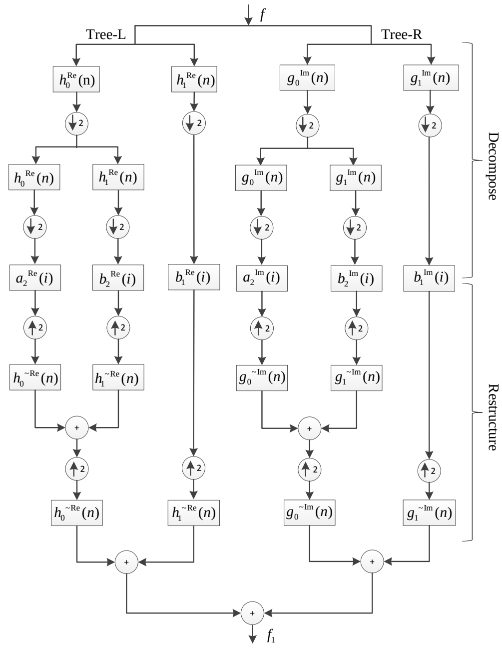

Fig. 7 The flow chart of DTCWT

The left subtree corresponds to the real part, and the right subtree corresponds to the virtual part, each contains a group of low pass and high pass filters respectively. The two sets of filters constitute Hilbert transform pairs, which make the DTCWT approximate analysis[7].

The delay of the corresponding filter between the real tree and the virtual tree is a sampling interval, the sampling location of the virtual tree is always in the middle of the real tree, in order to make the data extracted from two trees complementary, reduce the loss of information, and achieve the approximate translation invariance[8].

DTCWT can decompose the low frequency wavelet coefficients of each layer of the pulse wave signal, and use threshold to remove noise from high frequency wavelet coefficients, thus to get the noise-removed pulse wave signal.

5.3 Data Calculation

The original calculation formula of blood oxygen saturation is:

$$SpO_2 = \frac{C_{HbO_2}}{C_{HbO_2} + C_{Hb}} \times 100\% \tag{5}$$

By using Beer-Lambert Law and the principle of photoelectric conversion, the formula of blood oxygen saturation can be converted.

$$SpO_2 = A\cdot(\frac{I_{AC}^{\lambda_1}/I_{DC}^{\lambda_1}}{I_{AC}^{\lambda_2}/I_{DC}^{\lambda_2}})^2 + B\cdot\frac{I_{AC}^{\lambda_1}/I_{DC}^{\lambda_1}}{I_{AC}^{\lambda_2}/I_{DC}^{\lambda_2}} + C \quad (6)$$

As shown above, A, B and C are the fitting coefficients of the quadratic function curve, λ1 and λ2 are red and infrared wavelength, IAC and IDC are AC component and DC component of pulse wave.

The pulse rate indicates the number of pulses per minute, if n represents the number of sampling points, f represents the sampling rate, R represents the pulse rate, then:

$$R = \frac{60f}{n} \quad (7)$$

6. Experiment and Analysis

The pulse wave signals collected by photoelectric conversion inevitably contain a lot of noise: including low frequency interference by breathing, high frequency interference by Arteriole pulsation [9], and frequency aliasing interference by movement[10].

There are many burrs and inevitable baseline drift in the original pulse wave signal, as shown in Figure 8. When the signal is processed by morphological filtering and DTCWT, the waveform becomes more smooth, and the baseline drift is also suppressed. As shown in Figure 9.

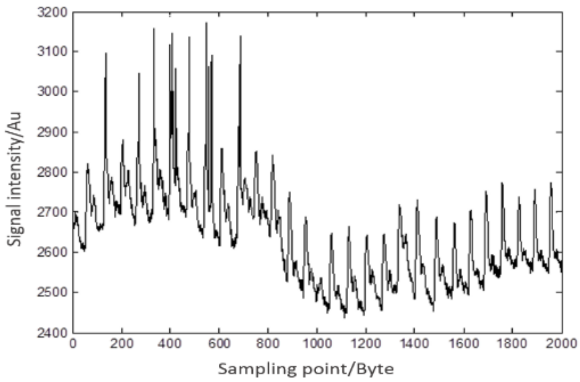

Fig. 8 Original pulse wave signal

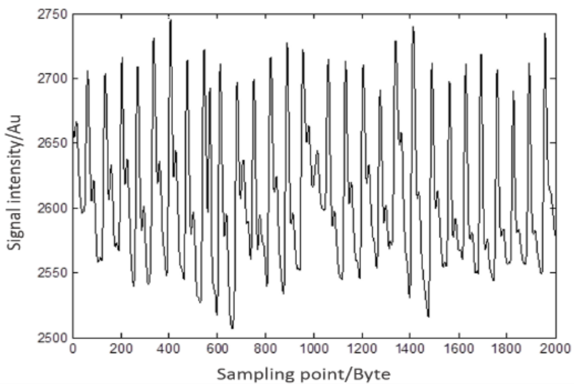

Fig. 9 Filtered pulse wave signal

The equipment consists of the glove, blood oxygen acquisition devices, and the mobile phone app, as shown in Figure 10.

Using this device and the standard monitor PC-304 to collect a person's physical parameters at the same time, the results are shown in Table 1 and Table 2.

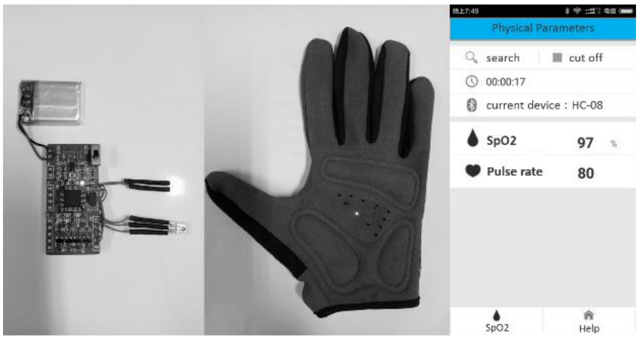

Fig. 10 Device prototype

Table 1 Comparison of blood oxygen saturation

Time	Device	PC-304	Error rate
1	94%	97%	3.09%
2	97%	97%	0%
3	95%	96%	1.04%
4	98%	96%	2.04%
5	98%	97%	1.03%
6	95%	96%	1.04%
7	96%	98%	2.04%

Table 2 Comparison of pulse rate

Time	Device	PC-304	D-value
1	78	82	4
2	86	88	2
3	90	87	3
4	85	92	7
5	82	86	4
6	86	89	3
7	83	88	5

As shown above, compared with the medical equipment, the error rate of the oxygen saturation calculated by the device is within 3.5%, and the D-value of pulse rate is within 8 times, so it can meet the actual demand.

Testing the power consumption of the device, as shown in Table 3, if powered by a 310mAh lithium battery, the duration of the device is nearly 14 hours.

Table 3 Power consumption test

Mode	Voltage/V	Current/mA	Power/mW
work	3.7	22.01	81.44
sleep	3.7	17.70	65.49

7. Conclusion

At present, it is lack of a complete system scheme for monitoring oxygen saturation under the dynamic environment. The design provided in this article is of good practicability, it can be applied to the field of exercise and fire-fighting, and it is significant for life protection.

References

[1] Jie Chen, WenYuan Jian, JunGuo Duan: Research and application of Retinal Oxygen Saturation Measurement Technology [J]. Medical Journal of West China, 2013, (11): 1740-1741+1744.

[2] YanLi Liu, WeiSong Zhao, HaiKun Li, FangBin Wang: Research on Removing Baseline Wandering of Pulse Wave Signal Based on Morphological Filter [J]. Journal of Hefei University of Technology, 2011, (04): 525-528.

[3] JiZhong Wang, ZhiWu Wang, GuoZheng Yan, DaSheng Liu: Fast filtering and real-time algorithm design for wireless SpO2 nodes [J]. Beijing Biomedical Engineering, 2015, (06): 595-599.

[4] KINGSBURY N G: The dual-tree complex wavelet transform: A New Technique for Shift Invariance and Directional Filter [J]. IEEE Digital Signal Processing Workshop, 1998, 98(1): 2-5.

[5] Selesnick I W, Baraniuk R G, Kingsbury N C: The Dual-tree Complex Wavelet Transform [J]. IEEE Signal Processing Magazine, 2005, 22(6): 123-151.

[6] WenTao Liu, Hong Chen, XiaoXia Cai, JunTong Liu: Signal Denoising Algorithm Based on Dual-tree Complex Wavelet Transform [J]. Fire Control & Command Control, 2014, (12): 84-87.

[7] Miao Wen, Cheng Wang, LiHong Bai: Motion Artifact Reduction of PPG Signals Based on DTCWT and cICA [J]. Chinese Journal of Medical Physics, 2015, 32(2): 229-233.

[8] ZhiZeng Luo, ZhenDing Zhou, Ying Zhou, HaiYang He: The Application of DTCWT Feature in Recognition of Motor Imagery [J]. Chinese Journal of Sensors and Actuators, 2014, 27(5): 575-580.

[9] QingYang Han, BingYu Li, XiaoDong Wang: The Method of Simultaneously Removing Breathing Baseling and High-frequency Noise in Pulse Wave Signal [J]. Chinese Journal of Medical Physics, 2014, (02): 4801-4805.

[10] YuShun Gong, BaoMing Wu, DanDan Gao, Hong Jiang, QingGuang Yan: Adaptive Elimination of Motion Artifact Separation During Oxygen Saturation Monitoring in Ambulant Environments [J]. Space Medicine ＆ Medical Engineering, 2012, (04): 266-270.