Acta Technica *62* No. 3A/2017, 13–20

Physiological indexes collection system for multifunctional gyms based on FFT and photoelectric sensor

Xiao Yang[1]

Abstract. Pulse oximetry is a continuous and noninvasive instrument that is convenient to detect arterial oxygen saturation. Because of its defects in system design and signal processing, there is a need for us to discuss and improve its measurement accuracy, repeatability and stability. In this paper, we propose a kind of multifunctional fitness monitor based on FFT and photoelectric sensor. It can analyze the blood oxygen saturation and heart rate of human body by adapting pulse noninvasive oxygen saturation detection method. Through collecting finger absorbed dose for red and infrared light, and amplifying it by controllable gain amplifier, then we can get the amplitude and frequency of AC electrical signal by the FFT. Firstly, we can complete the function of signal acquisition and automatic gain judgments as well as signal processing by using PIC24FJ128GA010. Finally, we need to demarcate the result by pulse blood oxygen simulator. In addition, the system also introduces the pedometer function based on acceleration sensor MMA7260 in order to enhance the practicability of fitness monitor. At the same time, the system also can obtain the dynamic physiological signs during the fitness process.

Key words. Fourier analysis, oxygen saturation, signal processing.

1. Introduction

Pulse oximetry has been widely used in clinical practice and becomes an indispensable clinical diagnostic device [1]. Its convenient operation and non-intrusive real-time measurements have essentially replaced the traditional blood measurement in vitro. Pulse oximetry can be used for continuous oxygenation estimation, especially in the operation of critical patients. It can quickly provide blood oxygen information and avoid the potential risk with arterial jacking method. In the emergency room, if the oxygen saturation can be continuously monitored by oximeter, then the ventilation can be conducted safely and alternately. In the treatment of patients requiring continuously adjuvant oxygen therapy, the pulse oximeter is often used to determine the oxygen requirement [2]. For patients with chronic obstructive

[1]Shaanxi University of Science and Technology, Shaanxi, 710021, China; E-mail: xxiaoyangsxust@163.com

tracheal disease, due to sleep apnea syndrome or nocturnal hypoxia saturation, they often require oxygen oximetry for sleep oxygen saturation study [3]. It is very difficult to collect neonatal blood, so no-damage blood oxygen meter is useful for the neonatal monitoring. It can avoid the damage to brain, lung and eye by adjusting oxygen therapy. Currently, most of the fitness products on the market are only used to detect the specific physiological parameters of the body or just have completed the detection of sports data. It did not combine the two projects, so it cannot achieve a reasonable fitness effect.

Based on this background, this article designed a multi-functional fitness monitor to guide the user's fitness by a scientific way. This monitor takes the oxyhemoglobin saturation and heart rate of human as the fitness index by calculating user's physical activity.

The hardware is a oxygen saturation detecting system composed of photoelectric sensor and corresponding conditioning circuit and the micro-controller PIC24FJ128G A010. There is a good development in the aspects of pass-filter and the controllable gain to obtain physiological signals by transmission-type pulse method. We can obtain the physiological information of body's blood oxygen saturation and heart rate using the built-in high-speed A/D of PIC24FJ128GA010 SCM to collect signals and adopt micro-controller signal sampling, and using FFT algorithm to analyze the obtained data.

In addition, the system also implements the pedometer function. The speed sensor MMA726 gets the acceleration characteristics during exercise, then it will gain some fitness information such as the step number, time and distance through software calculation.

2. Theoretical basis and algorithm of blood oxygen saturation measurement

2.1. Lambert-Beer's law

Lambert-Beer's Law reflects the optical absorption law, it means that material absorbance is proportional to its concentration at a certain wavelengths [4]. The meaning of Lambert-Beer's Law is that only we choose a appropriate wavelength and measure its absorbance, then we can figure out the concentration of solution. According to Lambert-Beer's law, formula (1) shows the relationship between the incident light intensity and the absorption layer thickness as well as the concentration of the absorbent

$$I = I_0 \mathrm{e}^{-acl} \,. \tag{1}$$

In the above formula, I_O is the input intensity, I is the transmitting intensity, a is absorptivity of absorptiometic matter, c is the concentration of absorptiometic matter, and l is the trans-missive distance (optical path) of absorptiometic matter.

2.2. The measurement principle of oxygen saturation

When the incident light passes through a certain uniform and non-scattering solution, its light absorption characteristics follow the Lambert-beer law. It can be described by formula

$$A = -\lg \frac{I}{I_0} = 2.303acl\,, \tag{2}$$

where A is the absorbance.

3. Design for measuring oxygen saturation

3.1. Hardware structure for measuring oxygen saturation

The hardware part is mainly composed of microprocessor, lighting drive, fingertip photoelectric sensor, amplifier, baseline adjustment circuit, high-speed A/D, D/A conversion and display. Pulse oximetry hardware principle diagram is shown in Fig. 1.

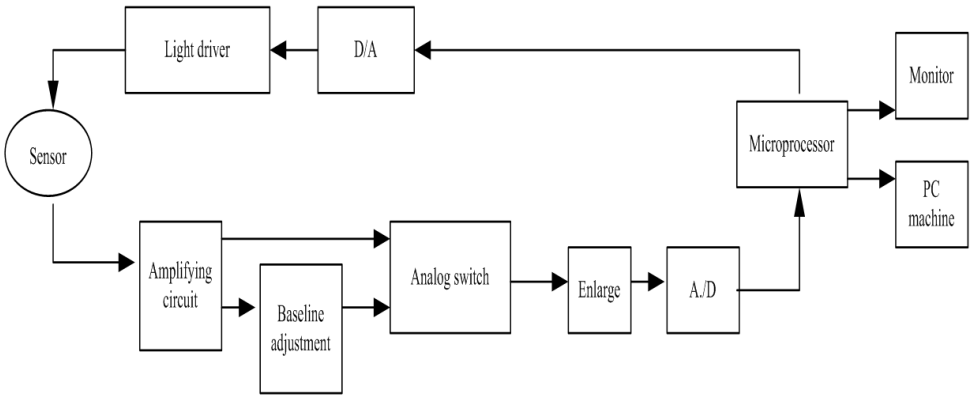

Fig. 1. Oxygen saturation detection block diagram

It will appear a driving signal with 660 nm and 940 nm infrared light through D/A conversion to the light source drive circuit. The light source drive circuit amplifies the signal and sends it to the red and infrared light emitting diodes placed side by side on the upper arm, sending optical pulse. The photoelectric detector on lower arm will transform it into electrical signals through the red light and infrared light on finger artery vessel. The intensity of the photoelectric signal detected by the photodetector is related to the size of the degree of absorption which the light signals penetrates the finger portion and is absorbed by the tissue, bone and blood.

Because the concentration of HbO_2 and Hb in blood changes cyclically with the pulse of the blood, so their absorption for light is also changing, thereby the output signal intensity of the photodetector also change with the concentration of HbO_2 and Hb in the blood. The light absorption curve of HbO_2 and Hb is shown in Fig. 2.

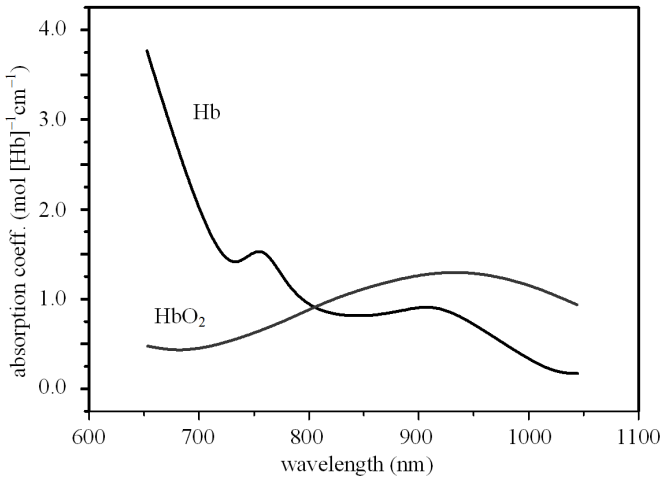

Fig. 2. Light absorption curve of HbO_2 and Hb

3.2. Software design

The system's software includes control software of non-invasive pulse oximeter microprocessor and analysis software achieved intelligent monitoring for oxygen saturation on PC. Here is no longer discussed in detail about the former.

The development of portable medical equipment and PC interface software can not only expand its function, but also achieve desktop or composite functions combined with PC. The system uses the powerful function of VC6.0 to develop and design the interface software of PC and oximeter and the data analysis software based on PC. It has the functions of data communication, intelligent analysis, storage, display and print result report [6].

4. Realization of blood oxygen saturation with Fourier analysis algorithm

The blood oxygen saturation algorithm proposed in this paper is mainly composed of three parts: signal acquisition, automatic gain judgment and Fourier signal analysis.

1. Signal acquisition: signal acquisition is mainly responsible for the LED tube drive and signal acquisition and conversion, in which the signal acquisition and conversion use the 10-bit high-speed A/D converter in microcontroller PIC24FJ128GA010. We can get the AC and DC signals with oxyhemoglobin saturation and heart beat through the A/D conversion [7].

2. Automatic gain judgment: because the degree of attenuation of the specific light through the fingertips varies from person to person, in order to enhance the versatility, the system uses the controllable gain amplifier to amplify the AC signal.

The system dynamically adjusts the gain of the controllable gain amplifier by judging the difference between the maximum value of the AC signal and the reference positive level (Vcc) of the A/D converter, and then makes sure the final data accounting for more than 2/3 of the Vcc to improve the system accuracy [5].

3. Results calibration: According to Lambert-Beer's law, when it is thought that the change of the attenuation of the light at the fingertip is mainly caused by hemoglobin, its transmitted light intensity can be expressed by the following the formula

$$I = I_0 \times \mathrm{e}^{-K_0 L_0 C_0} \times \mathrm{e}^{-K_{\mathrm{HbO_2}} L C_{\mathrm{HbO_2}}} \times \mathrm{e}^{-K_{\mathrm{Hb}} L C_{\mathrm{Hb}}} . \tag{3}$$

The attenuation of light is caused by other tissues on the optical path. The absorbance of this part of the tissue does not change with the pulse. Symbols K_0, C_0 and L_0 denote the total absorption coefficient, material concentration of light absorption and the optical path length.

5. Results and discussion

In this paper, we use pulse-type non-invasive blood oxygen saturation detection method to collect the absorption of red light and infrared light through photoelectric sensor, and then we can get the digital information about oxygen saturation and heart rate through hardware filter, amplification and Fourier analysis algorithm of software. The step-by-step circuit system composed of acceleration sensor have achieved the pedometer function. The detection signals of blood oxygen saturation and heart rate information is shown in Figs. 3 and 4.

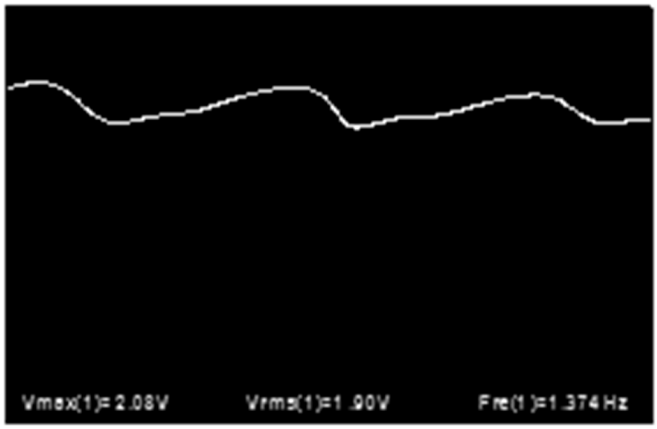

Fig. 3. Overlay chart after the filter

The sensor module generates a current signal with a degree of light attenuation, and converts the D/A into a voltage signal to form an AC/DC superimposed signal as shown in Fig. 3. After sampling for this signal, we can get the DC value corresponding to red (infrared) through a software filter. Through the bandpass filter,

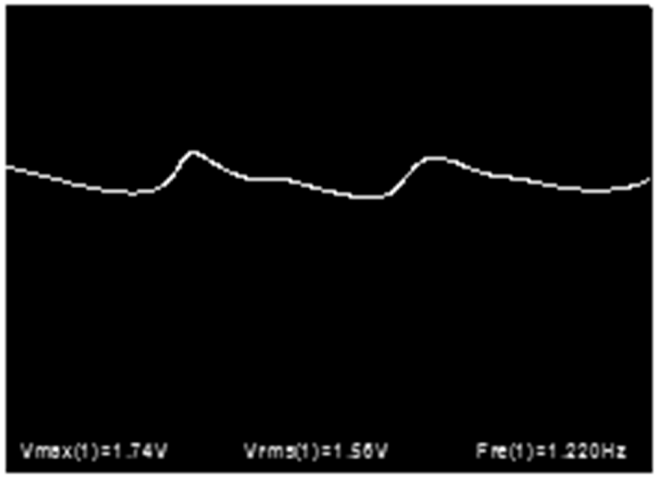

Fig. 4. Non-amplified AC signal chart after separation

superimposed signal forms a waveform shown in Fig. 4.

6. Conclusion

The multifunctional fitness monitor designed in this paper is mainly composed of two parts: the oxygen saturation, the heart rate acquisition and processing module and the step-by-step control analysis module based on the acceleration sensor. Using the photoelectric sensor, the acceleration sensor MMA7260 and the 16-bit microcontrollers PIC24FJ128GA010, etc., constitute the hardware system of this design that can analyze human signals through FFT analysis, adaptive step algorithm and digital filtering. Physical test results show that oxygen saturation accuracy proposed in this paper reach to more than 95 %, heart rate reach to 0.01 Hz. In this paper, the design of multi-functional fitness monitor has achieved the combination of physiological indicators and sports information and has provided a guiding basis for scientific movement.

References

[1] C. De La Merced Díaz-González, M. De La Rosa Hormiga, J. M. Ramal López, Y. Déniz Rivero, M. S. Marrero Morales: *Concordance among measurements obtained by three pulse oximeters currently used by health professionals.* Journal of Clinical and Diagnostic Research *8* (2014), No. 8, 211–220.

[2] S. Garcia-Gutierrez, A. Unzurrunzaga, I. Arostegui, C. Esteban: *The use of pulse oximetry to determine hypoxemia in acute exacerbations of COPD.* Journal of Chronic Obstructive Pulmonary Disease *12* (2015), No. 6, 613–620.

[3] A. V. Dunaev, V. V. Sidorov, A. I. Krupatkin, I. E. Rafailov, S. G. Palmer, N. A. Stewart, S. G. Sokolovski, E. U. Rafailov: *Investigating tissue respiration*

and skin microhaemocirculation under adaptive changes and the synchronization of blood flow and oxygen saturation rhythms. Physiological Measurement *35* (2014), No. 4, 607–621.

[4] A. Kachko, L. V. van der Ham, L. F. G. Geers, A. Huizinga, A. Rieder, M. R. M. Abu-Zahra, T. J. H. Vlugt, E. L. V. Goetheer: *Real-time process monitoring of CO_2 capture by aqueous AMP-PZ using chemometrics: Pilot plant demonstration.* Industrial & Engineering Chemistry Research *54* (2015), No. 21, 5769–5776.

[5] P. Chen, D. G. Zhao, D. S. Jiang, J. J. Zhu, Z. S. Liu, J. Yang, X. Li, L. C. Le, X. G. He, W. Liu, X. J. Li, F. Liang, B. S. Zhang, H. Yang, Y. T. Zhang, G. T. Du: *The thickness design of unintentionally doped GaN interlayer matched with background doping level for InGaN-based laser diodes.* AIP Advances *6* (2016), No. 3, paper 035124.

[6] R. Di Capua, F. Offi, F. Fontana: *Check the Lambert–Beer–Bouguer law: A simple trick to boost the confidence of students toward both exponential laws and the discrete approach to experimental physics.* European Journal of Physics *35* (2014), No. 4, paper 045025.

[7] J. Yan, G. Bin: *Research on an anti-motion interference algorithm of blood oxygen saturation based on AC and DC analysis.* Technology and Health Care *23* (2015), No. S2, 285–291.

Received May 7, 2017