A Novel Sphygmogram Sampling and Self-Adjusting Scheme for e-Home Healthcare

Wei Xuan Fang[1], **Ming Chui Dong**[1], **Wai Kei Lei**[2], **Xiang Yang Hu**[3]
[1]Faculty of Science and Technology, University of Macau, Macau SAR, China
[2]Institute of Systems and Computer Engineering, Macau SAR, China
[3]The 5th Affiliated Hospital of Sun Yat-sen University, ZhuHai, China

Abstract - *Pulse wave transmit time method has been used to estimate blood pressure by simultaneously measuring electrocardiogram & pulse signals* [1]. *Most researchers use photo reflective sensor to capture photoplethysmograph (PPG) signal by attaching sensor on finger tip. However, such a way would interfere hands in operating further the e-home healthcare system, plus PPG has flatter morphological shape* [2] *which is not adequate for searching feature points. Thus the piezoelectric ceramics is selected to acquire sphygmogram (SPG) signal with sharp morphological shape from wrist. Using such a way can free fingers to operate the e-home healthcare system. A SPG sampling scheme with signal conditioning circuit and relevant software for realizing signal amplitude and baseline-shift self-adjustment are proposed in this paper. A close-loop control is constructed between computer and micro control unit (MCU) such that to acquire the self-adjusted stable SPG signal. The testing results show out superior features of this scheme.*

Keywords: e-Home Healthcare, SPG, Signal Conditioning Circuit, Close-loop Control, Amplitude and Baseline-shift Self-adjustment

1 Introduction

Pulse signal can be sampled from different positions on human body, such as finger tip, wrist, chest, leg or any place with underneath carotid and radial artery. Since photo reflective sensor has been developed in recent years, most researchers choose finger tip as measurement position [3-6], such as ring-type PPG signal measurement device proposed by Chinese Univ. of Hong Kong. However, such a way is uncomfortable due to the space between fingers is limited for a ring-type device, which contains signal conditioning and wireless communication circuits and battery. Moreover, PPG has flatter morphological shape which is not adequate for searching feature points. Selecting other positions, such as chest and leg cannot get stronger signal, plus sticking the sensor on skin is even more uncomfortable. Alternatively, position on wrist has strong pulse signal which can be easily found out by most people, plus the SPG has sharp morphological shape which is good for searching feature points accurately, better still entire measurement device can be miniaturized as a watch-type, thus has extensive application foreground in e-home healthcare. Consequently, location of radial artery is selected for pulse acquisition in this paper.

The hospital used medical instruments having SPG acquisition function from wrist generally is large and the price is too expensive for home user. In addition, they need professional to adjust system parameters and record signal, eliminate existing external disturbance during SPG acquisition. To tackle such a problem, a home used SPG sampling scheme with self-adjusting technology is proposed in this paper, which can record a stable SPG waveform and transmit it to computer through universal serial bus (USB). Following content firstly introduces scheme structure and depicts each module; then explains the designed signal conditioning circuit and shows software flowchart for signal control & transmission; finally presents signal amplitude and baseline-shift self-adjustment method for SPG acquisition.

2 Sampling and self-adjusting scheme

A filmy passive piezoelectric transducer with 3.5cm diameter and 0.5mm thick is constructed as SPG acquisition sensor which transfers mechanical oscillation to electrical signal through piezoelectric effect [9]. His allowed pressure range is -500~5000mmHg with sensitivity of 2000µV/mmHg. Elastic band is used to attach transducer on wrist.

As shown in Fig. 1, the scheme is consists of six functional modules. The piezoelectric transducer transfers pulse signal to electrical waveform. Through signal conditioning circuit the amplitude of this SPG signal is processed as one within analog-to-digital (ADC) required range 0~5V. The signal conditioning circuit includes pre-amplifier, baseline-shift and filtering circuits. The refractory missions of this module are that greatly reduce signal phase delay to less than 40 degree, and keep the signal to noise ratio (SNR) being larger than 10dB. After that, the analog SPG is digitized in MCU module by using ATMEGA88V, which contains six 10bit successive-approximation-type ADC input channels. MCU module is also designed as signal processing and transmission unit since it supports simple math

---

This work was supported by Science and Technology Development Fund (FDCT) of Macau S.A.R with project ref. No. 018/2009/A1: “Embedded-Link Monitoring Platform for Cardiovascular Healthcare”

calculation and has two programmable USARTs (universal synchronous asynchronous receiver transmitter) [10].

Output signal of MCU is sent to USB interface module through USART, where the latest device FT232R is selected. Software is constructed to graph and analyze the digitized SPG waveform on computer, in the meanwhile it sends information of waveform amplitude and baseline back to MCU to adjust digitizing SPG signal. This close-loop feedback endows scheme with amplitude and baseline-shift self-adjusting capability which helps to stabilize SPG waveform.

The onset point of SPG signal is lower than 0V, which indicates that the operational amplifier needs ±5V power supply, plus the ADC's reference voltage is 5V, using Max1680 and through USB port, computer provides such required powers.

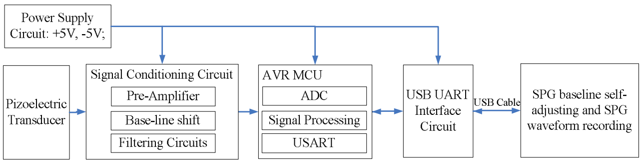

Fig. 1 Structure of Sampling and Self-Adjusting Scheme

3 Signal conditioning circuit

The transducer sampled SPG signal is -400mV~0.9V, in which often exist high-frequency interference noises and the baseline-shift affected by tightness of elastic band. The signal conditioning circuit processes SPG signal as one within ADC required input range and filters out noises. Multisim 8 is used to analyze circuit performance which offers bode plot and distortion analysis.

As shown in Fig. 2 and 3, a 1st order high pass filter (HPF) with 0.0008Hz cut-off frequency and large loading impedance (20MΩ) is designed to reduce signal's DC offset. The buffer circuit offers high input impedance and low output impedance. Then a pre-amplifier is added to increase SPG signal amplitude and SNR. Subsequently, a summing circuit is designed to shift signal minimum points to above 0V. Due to noise amplitudes are also increased after using pre-amplifier and summing circuit, a low pass filter (LPF) with 40.8Hz cut-off frequency is designed to reduce noises. Finally, ADC buffer is used to provide low output impedance.

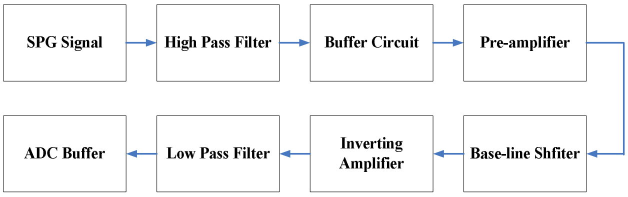

Fig. 2 Functional Diagram of Signal Conditioning Circuit

The frequency of SPG signal varies from 0.03Hz to 40Hz [8], thus a 10Hz sinusoidal signal with 0.6V offset and 1V peak-to-peak amplitude is used for simulation in Multisim. Eq. (1) determines HPF resistive and capacitive values. In Fig. 3, buffer circuit adds equivalent resistors to inverting and non-inverting nodes which compensate voltage drop caused by bias current and reduce total harmonic distortion (THD) by 0.017%.

$$f_c = \frac{1}{2\pi RC} \tag{1}$$

where f_c is cut off frequency, R and C are corresponding resistor and capacitor in HPF circuit.

The maximum peak-to-peak output voltage of operation amplifier (TL064) is 8V and the amplitude of SPG signal is about 1V. To satisfy ADC required range 0~5V and increase SNR, SPG signal is amplified by gain 3.35 so that let its amplitude be close to 4V. Eq. (2) determines resistors values in pre-amplifier circuit.

$$A_o = \frac{R_{38} + R_{39}}{R_{34}} \tag{2}$$

where A_o is gain, R_{38}, R_{39} & R_{34} are corresponding resistors in pre-amplifier circuit.

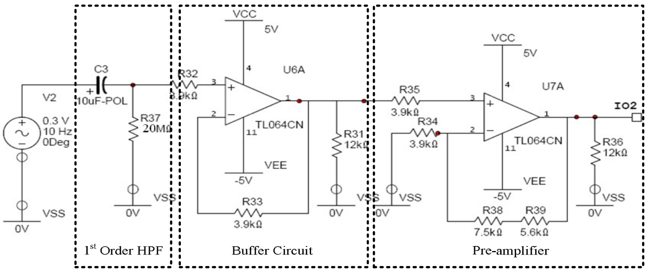

Fig. 3 HPF, Buffer and Pre-amplifier Circuits

After pre-amplifier, the negative amplitude of SPG signal becomes -1.34V with baseline located at 0V and noise amplitude is increased from 180mV to 460mV. Thus a summing circuit and an inverting amplifier are integrated together as shown on Fig. 4 to shift up baseline about 1.54V. Fig. 5 shows LPF and ADC buffer circuits. Through a 1st order LPF, noises are further reduced. All determined parameter values, that defined through simulation first and further adjusted by hardware experiment later are clearly marked in Fig. 3~5.

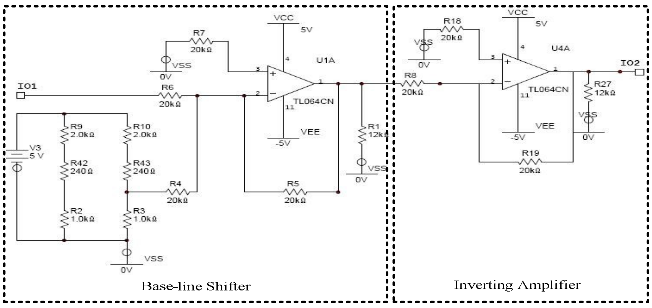

Fig. 4 Summing Circuit and Inverting Amplifier Circuits

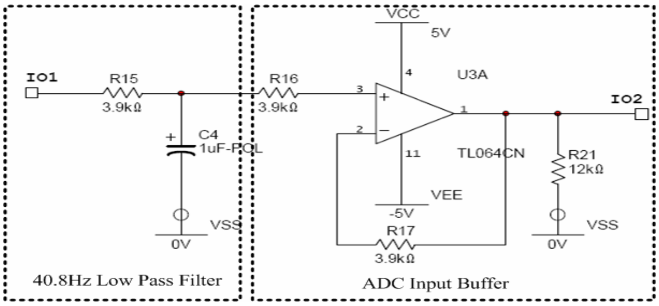

Fig. 5 LPF and ADC Buffer Circuits

The bode plot shown in Fig. 6 indicates effect of conditioning circuit on sampled SPG signal. When spectrum of SPG signal varies from 0.001Hz to above 40Hz, its amplitude decays quickly after 40Hz. The phase shift is zero degree within 0.03-1Hz and starts to increase after 1Hz, reaches -31degree at 40Hz. Eq. (3) transfers phase shift at 40Hz to delay time as 2.08ms which is acceptable in this scheme. Fig. 7 shows out the comparison between original sampled SPG signal and processed SPG signal after signal conditioning. The amplitude of processed SPG is within ADC required range (0~5V) with baseline located at about 1.5V. Moreover, its SNR is increased from 7.48dB to 12.7dB and satisfies design requirement (>10dB).

$$T_{pd} = \frac{\phi}{360}\frac{1}{f_x} \qquad (3)$$

where ϕ is phase delay in degree, T_{pd} and f_x are corresponding propagation delay time and frequency [7].

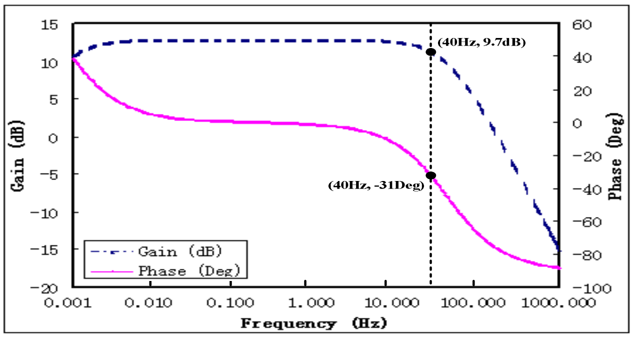

Fig. 6 Bode Plot of Signal Conditioning Circuit

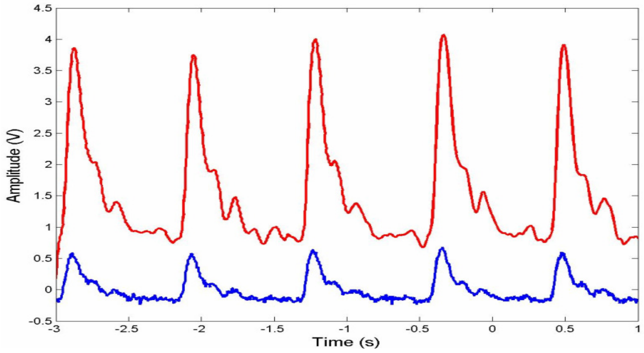

Fig. 7 Comparison between Original Sampled SPG (blue) and Processed SPG (red) Signals

4 Close-loop MCU control

Microcontroller ATMEGA88V supports C language in-system programming, thus it is programmed to control ADC, signal conditioning, timing and USB data transmission. Fig. 8 shows flowchart of MCU Control Program.

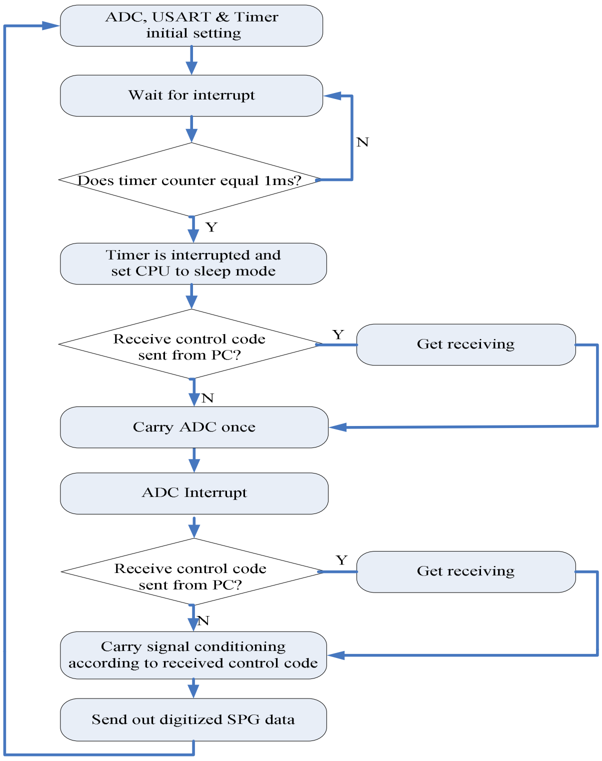

Fig. 8 Flowchart of MCU Control Program

In initial setting of MCU, the sampling frequency of ADC is set to 1000Hz and baud rate to 38400/s. Timer and the interrupt receiver are all enabled. Then MCU control program waits for interrupt signal. Once timer counter equals 1ms, timer is interrupted and set CPU to sleep mode. MCU carries ADC once with less power consumption and obtains smaller noise from I/O periphery equipment due to CPU is in sleep mode. Subsequently, ADC interrupt wakes up MCU and stores digitized SPG data. Finally, MCU carries signal conditioning according to received control code and send out finalized digitized SPG data using USART. During whole procedure, once get the receiving interrupt MCU stores control code sent from PC.

5 Amplitude and baseline-shift self-adjusting method

Ideally SPG baseline can be stably located at 0V after signal conditioning, but the home-user's improper operation in SPG measurement might shift SPG waveform to saturation or cutoff area and cause distortion. To tackle such an uncertainty and imprecision problem, an amplitude and baseline-shift self-adjusting method is proposed in this paper, which adjusts SPG baseline & amplitude, minimizes SPG distortion and lets SPG waveform totally satisfy the sampling criteria, then starts recording SPG automatically.

C++ program is constructed to realize this self-adjustment function and automatic SPG recording. Once receives SPG waveform from MCU, it compares its amplitude with sampling criterion every second. The highest point of SPG waveform is required to be larger than 4V but smaller than 5V; the lowest point must be lower than 1V but larger than 0V. When this sampling criterion is satisfied stably and continuously for 10 seconds, software system will start recording SPG waveform occurred in these 10 seconds. If the sampling criterion cannot be satisfied, software system starts to analyze amplitude and baseline of SPG waveform, and feedbacks control code to MCU. This hardware and software integrated, analysis and feedback loop between computer and MCU form a close-loop control which speeds up the sampling and guarantees the quality of sampled SPG waveform. Obviously it is a prominent brightness in such a novel scheme.

Actually, the highest and lowest points of SPG waveform are separately used to estimate amplification and baseline adjusting degree. Three ranks of amplification degree A1, A2, A3 and three ranks of baseline-shift degree B1, B2, B3 are defined. As shown in Fig. 9, software system analyzes the amplitude of input SPG waveform, classify its highest and lowest points according to above defined ranks. This analysis follows two rules: (1) if the highest point is larger than 5V, the amplification degree decreases one rank. (2) if the lowest point is lower or equals to 0V, the baseline-shift degree increases one rank. Therefore, the software system determines amplification and baseline-shift adjusting rank and feedbacks the control code to hardware MCU to adjust its digitizing SPG signal accordingly. This self-adjusting happens every second until the SPG waveform satisfies the sampling criterion. If the highest and lowest points of SPG waveform are not located at defined ranges, which is caused by the elastic band is too tight or too loose, or the measurement position is wrong, then the software system will show out a message to notice user to re-tie elastic band or adjust the measurement position on wrist. Fig. 10 shows the results of prototyping system adapted this novel SPG sampling and self-adjusting scheme, which had been successfully used in our developed e-Home Healthcare system.

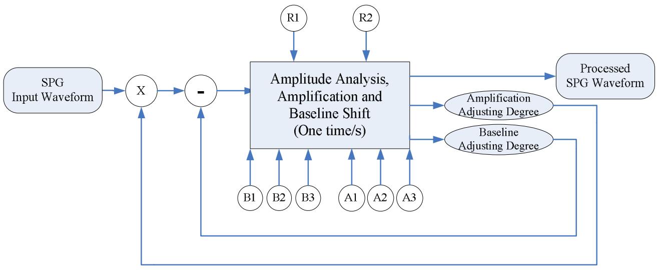

Fig. 9 SPG Amplitude and Baseline-shift Self-adjusting Method

Notation:

A1: the SPG highest point is located in 5V~4V, use amplification gain 1;

A2: the SPG highest point is located in 3.5V~4V, use amplification gain 1.2;

A3: the SPG highest point is located in 3.5V~3V, use amplification gain 1.4;

B1: the SPG lowest point is located in 2V~1.5V, shift baseline down 1.5V;

B2: the SPG lowest point is located in 1.5V~1V, shift baseline down 1V;

B3: the SPG lowest point is located in 1V ~0V, do not shift baseline.

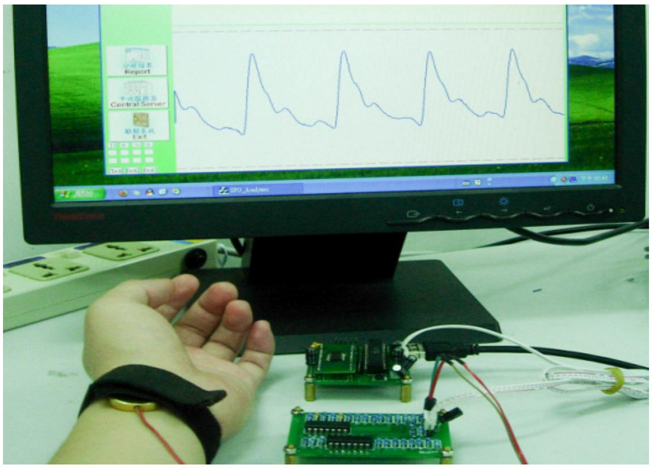

Fig. 10 Result of Prototyping System Adapted This SPG Sampling and Self-Adjusting Scheme

6 Conclusions

Demanded by pressure PWT method to estimate blood pressure, hands free SPG fast and stable sampling is a new challenge to all researchers working on e-Home Healthcare field. Towards to this mission, a SPG sampling scheme using piezoelectric transducer with signal conditioning circuit, close-loop control and relevant software for realizing signal amplitude and baseline-shift self-adjustment are elaborated and constructed. The test results show that this novel SPG sampling and self-adjusting scheme makes significant improvement in fast sampling SPG signal with tiny distortion and larger SNR.

By combining Bluetooth communication technology with this sampling scheme and designing watch-type measurement device instead of using elastic band to attach piezoelectric transducer to wrist, this scheme can offer better solution to cardiovascular monitoring and diagnosis system in e-home healthcare.

7 References

[1] Weixuan Fang, Mingchui Dong, Weikei Lei. "Novel System Sampling Multi Vital Signs for e-Home Healthcare"; 7th Int. Conf. on Information, Communications and Signal Processing, pp 1-5, Dec. 2009.

[2] Z. C. Luo, S. Zhang, Z. M. Yang. "Engineering Analysis for Pulse Wave and its Application in Clinical Practice"; The College of Life Science and Bio-engineering, pp. 19, 2006.

[3] D. C. Zheng, Y. T. Zhang. "A Ring-type Device for the Noninvasive Measurement of Aterial Blood Pressure"; Proceedings of the 25th Annual Int. Con. of IEEE EMBS, pp. 17-21, Sep. 2003.

[4] P. A. Shaltis, A. Reisner, H. H. Asada. "Wearable, Cuff-less PPG-Based Blood Pressure Monitor with Novel Height Sensor"; Proceeding of the 28th Annual Int. Con. of IEEE EMBS, pp. 908-911, Sep. 2006.

[5] J. M. Zhang, P. F. Wei, Y. Li, "A LabVIEW Based Measure System for Pulse Wave Transit Time"; Proceeding of the 5th Int. Con. on Information Technology and Application in Biomedicine, pp. 477-480, May 2008.

[6] P. Roncagliolo, L. Arredondo, A. Gonzalez. "Biomedical Signal Acquisition, Processing and Transmission Using Smartphone"; 16th Argenine Bioengineering Congress and the 5th Conference of Clinical Engineering, 2007.

[7] A. B. Williams, F. J. Taylor. "Selecting the Response Characteristic"; Electronic Filter Design Handbook, pp. 8-25, 2008.

[8] L. Y. Wei, P. Chow. "Frequency Distribution of Human Pulse Spectra"; IEEE Transactions on Biomedical Engineering, Vol.BME-32, No.3, Mar. 1985.

[9] X. Chen. "Pulse Signal Acquisition Based on LabView Software"; IEEE International Seminar on Future BioMedical Information Engineering, pp. 336-339, Jun. 2009.

[10] ATMEL. "8-bit AVR Microcontroller with 8K Bytes Programmable Flash"; ATMEL Corporation, Apr. 2007.