Playing and Acquiring Heart Sounds and Electrocardiogram Simultaneously Based on LabVIEW

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Abstract—**The paper describes a comprehensive system - a digital phonocardiogram (PCG) analyzer, which can acquire heart sounds and electrocardiogram (ECG) in parallel, synchronize the display and play of heart sounds and unite auscultation and check phonocardiogram. The hardware which controlled by MCU C8051F340, acquires heart sounds and ECG synchronously, and then sends them to indicators, respectively. Heat sounds are displayed and played simultaneously by controlling the moment of writing to indicator and sound output device. In clinical test, heat sound can be successfully located with ECG and real-time played.**

I. Introduction

THE heart is divided into four chambers. The upper champers are called atria while the lower chambers are called ventricles. Blood is squeezed by heart muscle from chamber to chamber. During the squeezing process, valves keep blood flowing as smoothly as possible into the heart and out to the body by automatically opening to let blood in from chamber to chamber and closing to prevent blood backflow. Heart sounds, the composite sound produced by myocardial systolic and diastolic, hoist valve, blood flow and cardiovascular vibration impact, contain a great deal of physiological and pathological information regarding human heart and vascular. By combining the advantage of heart sounds analysis and traditional cardiac auscultation; phonocardiogram analyzer can treat diagnosis of early stage cardiovascular disease in the following steps: space location of heart sounds can be distinguished by using a headset, the heart sounds can be shown by real-time waveform which includes the normal sound and murmur. Cardiac auscultation can be visualized; Data of heart sounds can be stored in the long run, be quantified and analyzed through modern signal processing methods.

Electrical and mechanical activities are the basic activities of heart. In each cardiac cycle, electrical activities are conducted prior to the mechanical activities [1]. ECG reflects electrical activity of the heart. While PCG records the mechanical heart activity (acoustic phenomena). Normal heart sounds are composed of S1, S2, S3 and S4. The pumping action of a normal heart is audible by the 1st heart sound (S1) and 2nd heart sound (S2). The 4th heart sound (S4) appears with a lower energy prior to the S1 and 3rd heart sound (S3) normally appears after S2. On the other hand, murmurs are created by damage valves and fusion of the valve leaflets. And recording ECG can serve as assistant to identify heart sounds. According to the valve theory and the hemodynamics theory [2], S1 starts 0.02 ~ 0.04 s after QRS and this process takes about 0.08 ~0.135 s; While S2 begins at the time the ECG T-wave end with a duration of 0.06 ~ 0.12 s; S3 appears in the ECG T-wave 0.12 ~ 0.20 s after S2 and continues for about 0.05 s; S4 comes 0.18 ~ 0.14s after the P wave in the ECG. Lehner [3] used the peak of R wave to estimate the starting point of S1. Baykal [4] and others extracted S2 by the time S2 appear in the later T-wave. To use segment heart sounds by ECG, there's a great need for simultaneously acquiring ECG and PCG in digital heart sounds analyzer.

II. System Description

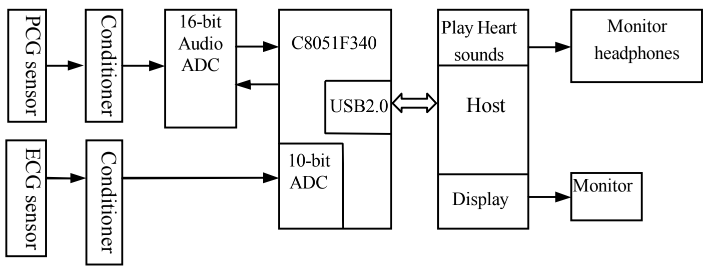


Fig 1 Hardware system diagram

As shown in Fig.1, heart sounds and ECG are data collected in parallel, they are converted to signals by sensors, filtered and amplified by a signal conditioning circuit, again converted into digital signal by ADC (Analog/Digital Convertor), then sent to the host through USB. By this way, the heart sound and ECG waveform can be shown on the screen, at the same time, the heart sounds are played. Because the large volume near patients easily affects the acquisition quality of heart sounds, heart sounds can play not by speakers but headphone. The headphone for auscultation must be selected carefully, it is required to wear comfortably and exclude external noise. In this paper monitor headphone is used and recommended.

A. Signal Acquisition

PCG sensor is made of eight auscultation-level standards Stethoscope OSMed130K and capacitor microphone. OSMed130K have double-faced chest piece, with one side diaphragm-shaped and the other bell-shaped, and could be rotated 180 ° for interactive use. Bell type chest piece acquires some minor vascular murmur or low-frequency sounds, and diaphragm type chest piece is used for collecting most of the other voices. Capacitor microphones (frequency response of 20 to 20 kHz, sensitivity 15 mv/Pa) can perfectly reflecting the heart sounds and noise. The heart sounds is mechanically amplified by Stethoscope firstly, transferred from capacitor microphone into a voltage signal which is filtered and amplified by conditioner. Because the sensor output signal is relatively weak and difficult to extract useful information directly, the preamplifier circuit is used to enlarge it about ten times firstly. But the signal includes much low-frequency noise (friction sound, breathing sound, the human interference signal, and offset drift of the preamplifier, etc.), which would lead to heart sounds signals be inundated. The signal can be extracted out from such interference by using a eighth order voltage-controlled voltage source high-pass filter with corner frequency at 1 Hz. As heart sounds range differs from person to person, to show waveform in appropriate range, adjustable amplifier is used to amplify the heart sounds. Processed analog signal is converted into a digital signal by a 16-bit audio ADC, and then be sent into MCU C8051F340.

ECG is collected by one-off ECG electrode to signal conditioning circuit. At this time ECG is weak and contains common-mode signal, the power line interference, baseline drift and electromagnetic interference. Conditioner comprises the high-performance low-noise pre-amplifier circuit, zero baseline circuit, low-pass filter and main amplifier. Pre-amplifier eliminates common-mode signal and enlarges the useful signal 20 ~ 30 times. The low-pass filter with cutoff frequency at 100 Hz applied in this paper is also a 50 Hz notch filter. It can attenuate the 50 Hz signal 40 dB and reserves the useful ECG below 100 Hz. The main amplifier enlarges the ECG 50 times again. Then the signal will be proceed to remove the baseline drift. Processed analog signal is converted into a digital signal by 10-bit ADC of MCU.

B. Synchronization Technology

ECG and PCG are parallel. To ensure them synchronous, please do the following:

--Firstly, same delay and phase shift in hardware acquisition circuit. For zero phase shifts, phase compensation shall take into consideration when designing; for same delay, similar signal processing circuit topology shall be ensured.

--Second, after the starting instruction from the host, the 16-bit ADC controlled by MCU and 10-bit ADC begin to convert data at the same time, the data package which is composed of the above converted ECG and PCG data are sent to the host through USB.

--Third, Data packages will be separated for PCG and ECG independently by the software. And zero phase difference is ensured when dealing again. The self-made sensor in this article has high sensitivity. The PCG separated from the data packets can be used to display directly without software processing. So there is no phase shift. But there still are power lines interferences in ECG signal; digital filter method is required such as an 8th order Chebycev-type low-pass filter with corner frequency at 35 Hz. There is phase lag which makes ECG behind PCG and PCG can't be located well by ECG. Butterworth bandstop filter with fl = 49.5, fh = 50.5 is chosen after experiments. ECG also achieves zero phase lag. Data collected before and after software processing showed that same delay and phase shift has been achieved, thus the ECG and PCG are synchronized.

III. SYNCHRONOUS ACQUISITION AND REAL-TIME PLAYBACK SOFTWARE

A. Synchronous Acquisition Implementation

The spectrogram of human ECG is about from 0.05 to 100 Hz, the major components of human PCG are below 500 Hz, and the murmur is below 1500 Hz. According to the sampling theorem, that is, the sampling frequency (fs) must be twice greater than the cut-off frequency (fc) of signal. Considering the requirements of late playing heart sounds sampling rate (8000 Hz, 11025Hz, 22050Hz, or 44100Hz), 400 Hz for ECG sampling and 8000 Hz for heart sounds sampling are introduced in the system.

16-bit ADC is used for PCG, and 10-bit ADC is used for ECG. So PCG data and ECG data are16-bit and 10-bit respectively. In order to achieve synchronous transmission, ECG data is converted into 16-bit in MCU. Two hundred PCG data, 10 ECG data, header and parity will compose of a package data as a unit. Data format is shown in Fig. 2.

Header	PCG	ECG	Parity

Fig 2 Data packet format

The communication between MCU and host uses USB. In the program, resource is set using the attribute nodes, including baud rate, bits per sample, parity, stop bit , flow control and so on [5]. 'VISA open', 'VISA close', 'VISA write' and 'VISA read' functions are used to complete communication.

In 'Acquisition.vi' programmed on LabVIEW, all kinds of variables such as PCG data file and ECG data file for temporary save, and selection of auscultation area should be initialized. There are five traditional auscultation areas, mitral valve area, pulmonary area, aortic area, secondary aortic area and tricuspid area. Because the influence of valve place and sound transmission, other right area could also be chosen, usually the loudest area should be chosen. When user click 'Acquisition' button on front panel, block diagram will set the serial port interface by property node , send start acquisition instruction, read data package and separate into PCG and ECG, show on front panel and play heart sounds simultaneously. While user click 'End' button, block diagram will send stop instruction, close USB, input patient information and save it, delete the temporary files, close progress, exit. Flow chart is shown in Fig.3.

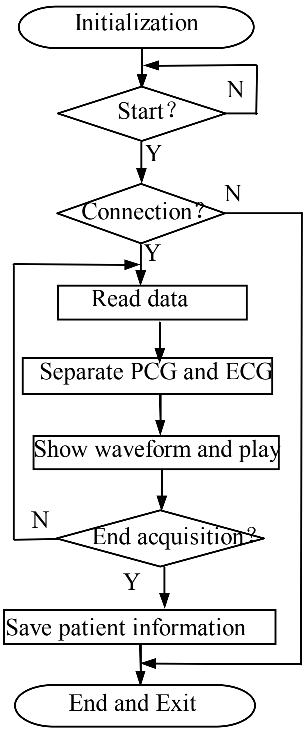


Fig 3. Flow chart

B. Real-time playback of heart sounds method

Traditional methods of playing heart sounds is that data file will be transformed to sound file after acquisition and be played by player, such as player deal with '*.wav' file. The drawback is that the collecting and playing of heart sound can not be down simultaneously. In other word, doctors could not achieve auscultation and observe the PCG at the same time. This paper takes advantage of the LabVIEW sound function to get Real-Time playing of current acquisition data, and to unite auscultation and observing PCG organically.

Main functions used in Real-time playing are following: a) SO Config.vi; b) SO Start.vi; c) SO Write.vi; d) SO Pause.vi ; e) SO Clear.vi. Function 'SO Config.vi' configures a sound output device and creates a sound output task ID. After you use this VI to configure the sound device, the device is in pause mode. You can use the function 'SO Write.vi' and 'SO Start.vi' to play the application data. Generally, the default device number is 0. Sound format input port is so important that it need to set appropriately, including setting up the sound quality as stereo or monaural, sampling rate (8000, 11025, 22050, or 44100) and bits per sample (8

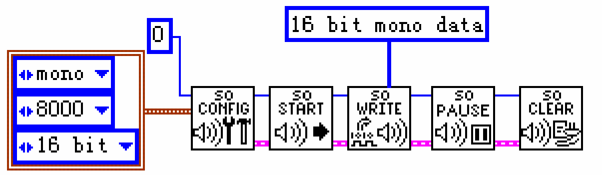


Fig. 4 Block diagram of playing heart sounds

bits or 16 bits per sample). The paper chose monaural, 8000 Hz sampling rate and 16 bits per sample. If setting isn't correct, it will lead to distortion of the voices. The function 'SO Start.vi' used to start a sound output operation associated with the task ID in. If there is no data in device cache, it does not play. The function 'SO Write.vi' writes data to the sound output device. If the device is running already, the data move to the buffer immediately. If the device is in pause mode, the data do not start playing until 'SO Start.vi' runs. Write any 16-bit monaural sound data to the internal buffers if sound format specifies 16-bit monaural data. Otherwise, this input is ignored. The function 'SO Pause.vi' pauses a sound output device, no data is lost and the current position is saved. The function 'SO Clear.vi' Closes the output sound device and releases any resource the device uses to the computer system. The block diagram of playing heart sounds is shown in Fig. 4. Firstly, configure the output device with below specifications: device Number 0, mono and the 8000 sampling rate, 16 bits per sample. Secondly, start device. As soon as the sound data to be played is written into the device, the sound is played immediately. Finally, pause the device, turn it off and release the resource.

If structure which control the process is not added between 'SO write.vi' and 'SO Pause.vi', even if the sound data to be played is written into the device and the device has been paused; heart sound can not be played, waveform displaying and sound playing can not been achieved simultaneously. Sound data put into the buffer and sent to the display must be synchronous. So it is crucial to put the 'SO Write.vi' and waveform display in the case structure of the

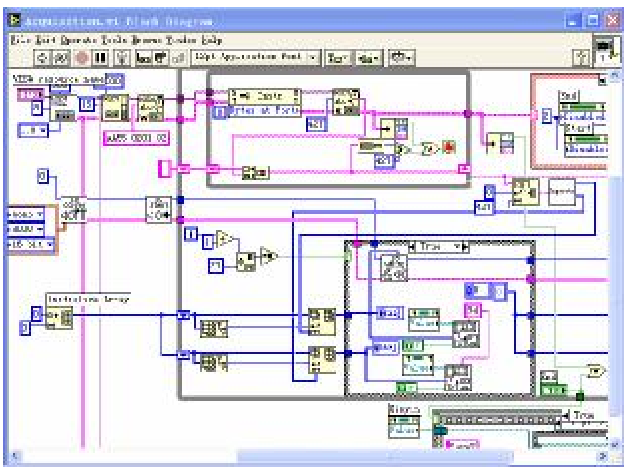


Fig. 5 VI block diagram

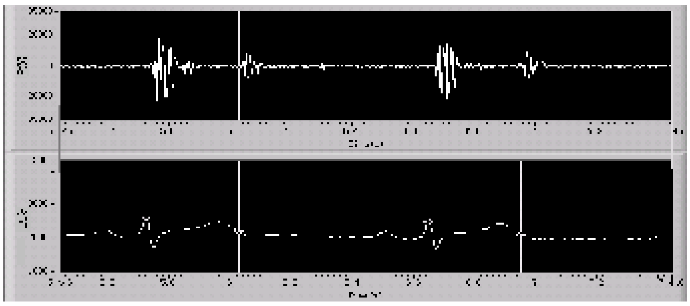
same loops structure. Specific procedures diagram is shown in Fig.5.

IV. CLINICAL TEST

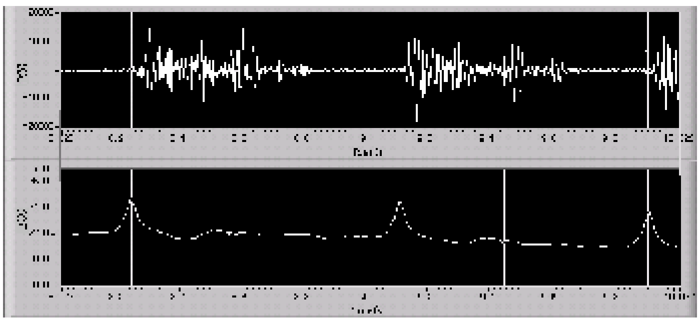
Clinical acquisition has been processed at Cardiology Department of the Second Affiliated Hospital, Chongqing Medical University. There are 25 normal heart sounds and 25 murmurs. The normal is shown in Fig.6 (a). The time waveform clearly shows the 'lub-dub' heart sounds without other component. No murmur can be heard from the headphone as the clinical auscultation. The abnormal (Wu xx, male, age 72) is shown in Fig.6 (b), and clinically judged as rheumatic heart disease, dual-phase murmur. As shown in the PCG, there is obvious murmur between S1 and S2, and between S2 and next S1. Dual-phase murmur can be heard from the headphone as the clinical auscultation.

V. CONCLUSIONS

Heart sounds are one of most important human acoustic signals. Developing heart sounds analyzer which combines the traditional clinical auscultation and Phonocardiogram advantage, quantify and analyze the heart sounds signal is of vital social and economic value. The system described in this paper *Playing and Acquiring Heart Sounds and Electrocardiogram Simultaneously* has combined traditional auscultation and PCG examination powerfully by simultaneously displaying real-time waveform and playing heart sounds. It can combine both sound and image, visualize auscultation, enable user to distinguish the location of heart sounds by ear, thus make up the deficiency and improve the diagnostic ability. Clinical trials show that ECG which simultaneously recorded with PCG could correctly locate heart sounds. The heart sounds features which can be used to judge disease can be identified by earphone. It can be useful for patient monitoring in homes, nursing homes, hospitals, medical transports, and veterinarian facilities, as well as for status monitoring of law-enforcement and rescue personnel. In the follow-up study, effort shall be made to perfect the method of quantitative analysis, and meanwhile focus on improving the sound quality of headphone.



(a) Normal heart sounds



(b) Abnormal heart sounds

Fig.6 Normal and abnormal heart sounds

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