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Design of a Seismocardiography Using Tri-Axial Accelerometer Embedded with Electrocardiogram

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***Abstract*—This paper presents a design of a seismocardiography. The device uses a triple axis accelerometer to measure the accelerations from the chest wall produced by the heart activities. The device also provides an electrocardiogram for heart disease diagnostic. The seismocardiogram and electrocardiogram are stored in a memory card and to be retrieved by a computer. The device was built using low cost, off-the-shelf components. It is easy to use and can collect data up to 10 hours without recharging battery or file transferring.**

***Index Terms*—-biological sensor, seismocardiogram, accelerometer, ECG, data logger.**

I. Introduction

The seismocardiogram (SCG) measures the forces generated by the contraction and relaxation of the heart. These compressive waves are produced primarily by both heart wall motion and blood flow [1]. A committee of the American Heart Association published a consensus report for the nomenclature for seismocardiography waveforms which remain in use today [2]. The classical seismocardiogram was demonstrated in the medical literature to significantly add to the diagnosis of heart disease. Important in those demonstrations is the conclusion that the seismocardiogram had considerable accuracy in the identification of early coronary artery disease. However, the complexity of recording the seismocardiogram led to the abandonment of the procedure, as other cardiac diagnostic techniques were introduced (e.g. echocardiography). Attempts using other techniques to record the seismocardiogram were marginally successful and published under a variety of names such as seismocardiography, ballistocardiography and apexcardiography [3]. Previous research using seismocardiography has been done since the 1930's and a small amount continues today [4-6].

The primary purpose of this design is to build a prototype seismocardiograph. The device will produce a classic seismocardiogram to trace reliability and accurately, the heart activities. The device also integrates a circuit that can detect and record simultaneously both the electrocardiogram (ECG) and the seimocardiogram. This biosensor device is a solid state device composed of: a tri-axial accelerometer (micro-electrical-mechanical system, MEMS device), and ports for external wires to collect heart rate (ECG; Lead II) and an on-board data storage capacity (an SD card), and a 3.7V Lithium polymer battery. The data are then retrieved to a personal computer.

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II. The Design

Fig. 1 shows the block diagram of the device. The main sensor is an accelerometer which detects the compressive waves from the heart wall motion. The signals from the sensor are appropriate filtered and amplified to a level to be sampled by analog-to-digital converters from a datalogger. The electrocardiogram signal is collected from the ECG electrodes. The ECG signal is also amplified and filtered. The datalogger samples and stores data into a 1GB mini-SD memory card.

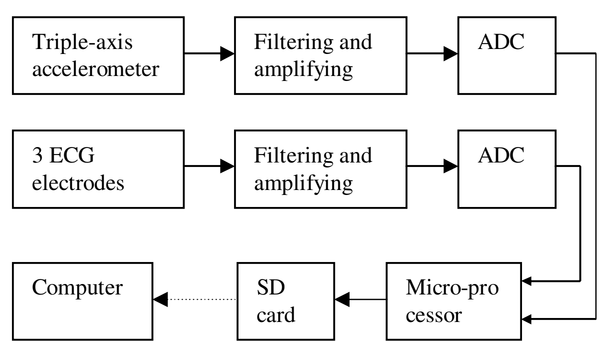

Fig. 1. System block diagram of the seismocardiograph.

The seismocardiogram sensor is a triple-axis accelerometer, MMA7260QT, made by Freescale. The sensor has a low power shut-down mode, high sensitivity output with selectable ranges (±1.5, 2, 4, and 6g). The accelerometer is mounted on a small printed circuit board (PCB). The MMA7260QT is supplied by a 3.3VDC and outputs an analog voltage for each of the three outputs. This voltage is in ratio to the measured acceleration and to the supply voltage (ratiometric). The three acceleration voltages are amplified and filtered. Amplification and filtering are to be described in the next section.

The ECG is a 3-lead circuit in which two electrodes are connected to the left and the right of the chest and the third electrode (i.e., ground) can be connected anywhere on the body. The differential ECG signal is to be amplified, filtered,

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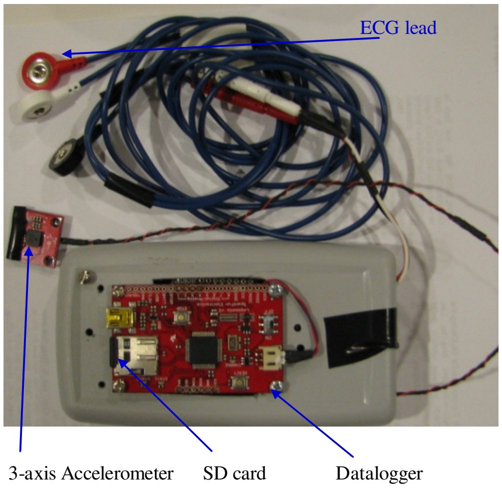
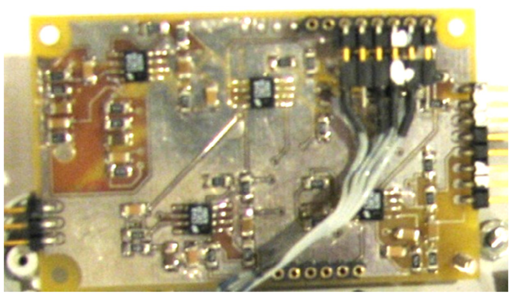
and fed to the analog to digital converter (ADC) as shown in Fig. 1.

Fig. 2 is the photograph of the designed seismocardiograph and its printed circuit board.



(a)



(b)

Fig. 2. Pictures of the seismocardiograph showing the datalogger, ECG leads, and accelerometer (a) and the PCB for the amplifying and filtering circuitries (b). The circuit boards and a 3.7V, 1100mAh LiPo battery are housed in a box.

The design uses an off-the-shelf datalogger made by Sparkfun Electronics, the Logomatic. Data are stored in a mini SD card of a maximum capacity of 1GB. The logger circuit includes a charge circuitry with overcharge protection to charge a 3.7V lithium polymer battery. The logger is used in the character triggered ADC mode. The triggered frames are delimited with carriage return and line feed characters for easy reading its 8 ADC channels. The channels to be sampled are selectable as on or off in a configuration file stored in the SD card. The sampling rate of these 8 ADC channels can be selected from 1Hz to 1000Hz depending on the number of channels to be sampled. In this application, a maximum of 400Hz is selected since only 4 channels are needed. The signals to be sampled are x, y, z of the accelerometer and the ECG. This sampling rate is sufficient to recover these signals. The Logomatic also includes a low dropout regulator. The 3.3V is regulated from the 3.7V LiPo battery. This voltage is also used in the amplifying and filtering circuits. The maximum current draw of the Logomatic is about 80mA.

Fig. 3 shows the schematic diagram of the amplifying and filtering circuits. The signals are filtered using 2 stages of low pass filter (LPF) with a cut-off frequency of 4Hz. All of the three axis signals use the same circuit as the shown in the schematic. The amplification gain for each axis of the accelerometer is about 1,200. The differential ECG signal is first amplified by the instrumentation amplifier A3 (AD623A) and then connected to the amplification and filtering as the same way as the 3 axes of the accelerometer. The total amplification gain of the ECG signal is about 2,500. All of the outputs are biased at 1/2Vcc (i.e., 1.65VDC). This bias gives the input signal swing from 0V to 3.3V to the analog to digital converters (ADC). There are 4 ADCs used in the system. Each ADC has a 10-bit resolution. The least significant bit (LSB) represents 3mV. This provides a 1.5mg/bit of acceleration for an accelerator setting of ±1.5g operation. Proper scaling and calibration of the signal amplitudes will assist in calculating the forces pushing from the heart to the chest wall.

III. Testing Results

Fig. 4 shows a typical SCG and its matching ECG taken from [7]. The ECG includes systole and diastole cycle as shown. The SCG also has a cycle closely related to the ECG as explained in [7]. The seismocardiogram contains waves corresponding to the peak flow across the mitral valve during early rapid filling (RF) of the left ventricle and during atrial systole (AS). The seismocardiogram also has a wave corresponding to isovolumic contraction of the left ventricle, with the point on the wave where it suddenly develops a negative slope coinciding with mitral valve closure (MC). The largest seismocardiographic wave is usually the point that corresponds with the peak flow across the aortic valve during rapid ventricular ejection (RE). These events are labeled in Fig. 4.

Fig. 5 shows the waveforms recorded by the designed seismocardiograph. The accelerometer is taped on the chest of the subject at the center where the ribs come together. It has been found through experiments that this is the best location to have strong seismocardiograms. The figure includes 3 cycles of the heart beat. There is ECG signal along with the 3 axis x, y, and z of the accelerometer. The accelerometer is mounted in which x axis is pointing to the right hand, the y axis is toward the feet, and the z is pointing outward from the chest. The subject is at supine position (lying on the back and having the face upward). The sampling rate of the ADC is set to be 400 samples per second.

Fig. 6 shows a closer look at one cycle of the heart activities on the z axis signal. All of the events described in Fig. 4 are identified. The other two axis (x and y) can also be used to build the seismocardiogram, for example, the y axis waveform has similar peaks of the z axis. Using all of the three axis waveforms will assist in fully comprehensive the heart activities and the events happen in the blood flow system. More analysis of the waveforms will reveal many needed information in heart disease, even the measurement of the true blood pressure as described in [8]. The device was put on the tests 110 times on various young, healthy people. Results were collected and analyzed to proved the device working properly and satisfactory.

A full charged 1100mAh LiPo battery lasts about 12 hours. The 1GB memory can store up to 40 hours of data collection at a sampling rate of 40SPS.

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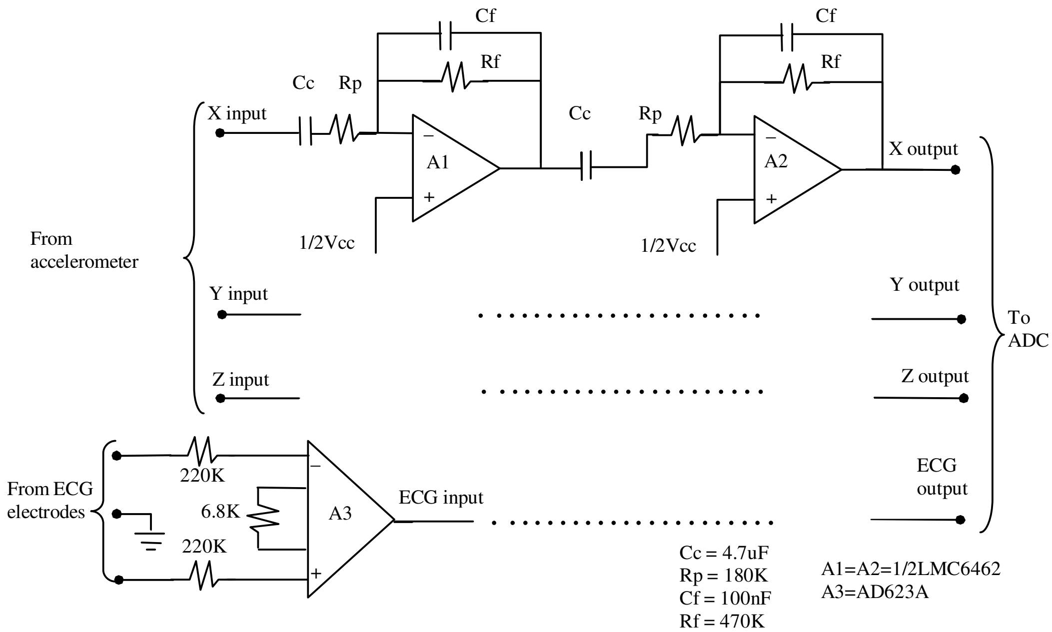

Fig. 3. Schematic diagram of the amplifying and filtering circuits.

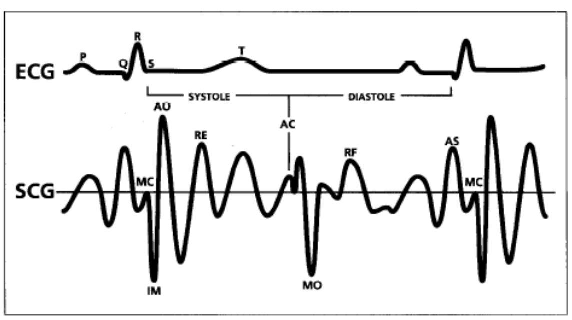

Fig. 4. A typical resting seismocardiogram (SCG) and matching electrocardiogram (ECG) [7].

Note: MC= Mitral (Valve) Closure
A0 =Aortic (Valve) Opening
RE = Rapid (Ventricu1ar) Ejection
MO = Mitral (Valve) Opening
RF = Rapid (Ventricular) Filling
AS =Atrial Systole
AC =Aortic (Valve) Closure

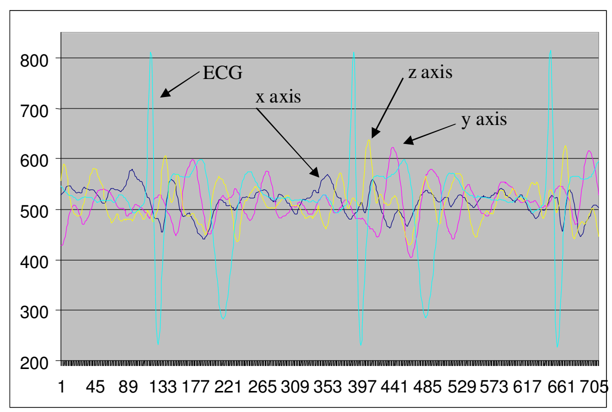

Fig. 5. A seismocardograph with ECG signal recorded on a 55 year old male volunteer in supine position.

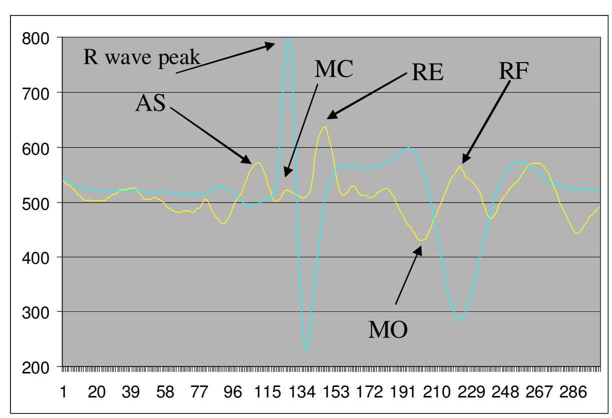

Fig. 6. Zoom in to one cycle to show the peak of the corresponding heart activity using z-axis (perpendicular to the heart)

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IV. Conclusion

A low cost seismocardiography has been designed and successfully tested. The device is small, simple to use and provides a high sensing accuracy. More tests are needed in a wider population at different age groups to verify its usefulness in diagnostic of heart disease and monitor heart activities. Wireless transmission can be easily implemented to replace the SD card for telehealth applications.

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