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Research paper

A Review on Vibration Analysis of Seismocardiography (SCG)

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Abstract

This paper reviews on the non-invasive cardiac diagnostic method using accelerometer. Currently, the clinical cardiac diagnostic tools that are available are acoustic stethoscope, electrocardiogram (ECG) and echocardiography. The ECG represents cardiac electrical activities that provide important information to diagnose diseases such as myocardial ischemia, infarction and arrhythmias. However, it is not very helpful to diagnose cardiac contractility dysfunction and valvular diseases. Echocardiography provides alternative solution to the problem. Based on the principle of ultrasound imaging, it can precisely capture the heart images that works in real-time. Nevertheless, it comes with high operational cost and requires a specialist who is an expert and properly trained. It is also not immediately available in most hospital and medical institutions. This review will emphasize on the technological trends of devices that are able to capture heart related diseases. The usage of accelerometer has gained lots of attention as its ability to detect micro-vibration is outstanding. It is placed on the surface of the chest and listens to the vibrations, which are produced by the operations of the valves. The ability to pick up such information somehow depends on many factors such as the sensor sensitivity, the sensor placement method, position and the extraction algorithm used. Each of these factors will be discussed and compared.

Keywords: *Seismocardiography, accelerometer, heart disease, cardiovascular*

1. Introduction

Heart disease generally refer to abnormally structure in the blood vessels of heart which lead to heart attack, chest pain or stroke. Some heart abnormal condition will affect heart's muscle, valves of rhythm also considered as forms of cardiovascular disease. Nowadays, technology improvement has brought more advance method in detection of cardiovascular disease including electrocardiogram (ECG), echocardiography, computerized tomography (CT) scan, magnetic resonance imaging (MRI) help in diagnosing patient's heart condition. According to a study conducted by [1], ECG output is insufficient to bring information of cardiac mechanical activities even it is composed of summation of cardiac electric signal. There are several work done by [2,3,4] developed a new way in detecting heart rate and respiratory rate using a single accelerometer. The position of accelerometer sensor attaching on human body as shown in Figure 1.

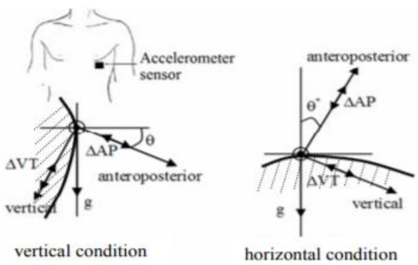

Figure 1: Sensor module location [1]

The accelerometer used is ADXL204 model, a biaxial accelerometer placed above the heart with its sensitivity is along the anteroposterior direction on the sagittal plane of human body and another one is along the vertical direction. ADXL204, is an analog type of accelerometer and data output need to be converted into digital bit, so they used an DAQ-6024E card, an analog to digital converter card used to sampling the data output with a frequency 1kHz, and data output is 14-bit resolution analog-to-digital conversion. Software used to analysis the data via Labview 7.0 software of National Instruments Inc. Due to vibration of heartbeat peak to peak amplitude is around 80mg, a high-resolution bit with at least of 13 bit of ADC converter is required to measure data of heart vibration with a very good resolution. However, for the experiment performed by [5] utilizing two acceleration sensors to record heart vibrations without need of ADC card. The sensor used is LIS3DSH, a digital type of accelerometer output with 16-bit resolution of data. The attaching position of sensor is at the front and back of torso. The signal output still has some noise and they used IIR bandpass filter for the data collected and eliminate noise outside of the respiration rate spectrum. Due to two accelerometer sensor or single sensor only can get the heart rate signal but cannot get the source of signal from any specific location of cardiac. Thus, an improved way had done with multi accelerometer sensor is implemented by [6] to identify location-specific feature points in a cardiac cycle corresponding to the four valvular auscultation locations. They used 4 accelerometer sensors (LIS331DLH) [7] positioning on the surface of chest as shown in Figure 2

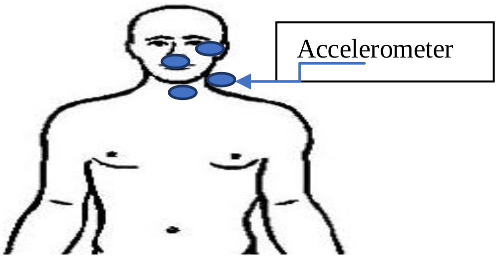

Figure 2: accelerometer sensors arrangement and position.

From figure 2, 4 accelerometer sensor array is used to collecting SCG data from heart beat vibration which will tranfer to computer to perform anlysis process by using Matlab software to convert the acceleration data into frequency by using FFT algorithm. The data collected will display as time domain in order to get the ventricular mapping.

1.1 Problem Statement

The acquisition SCG signal problem can be stated as follows:
How to arrange the accelerometer sensor array to perform a multi-channel SCG acquisition and what data supposed to be used in identifying the result is related to signal generated by cardiac mechanism motion?

2. Methodology

The problem is illustrated in figure 3 with showing location of SCG sensors and ECG to do data synchronize on SCG traces, echocardiographic images, ECGs, for feature points identification.

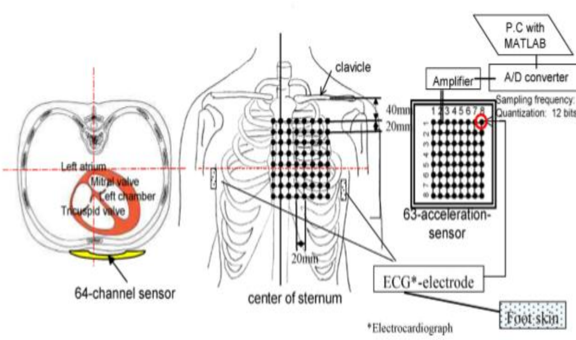

Figure 3: An experimental setup of multi-channel sensors for visualizing heart motion[6]

The output data of accelerometer is an acceleration data which will be computed through computer with Matlab software to analyze seismocardiogram (SCG) data. Heart rate signal with S1 and S2 phase will be shown in ECG data in which help in synchronuos with SCG data to identify each specific valve.

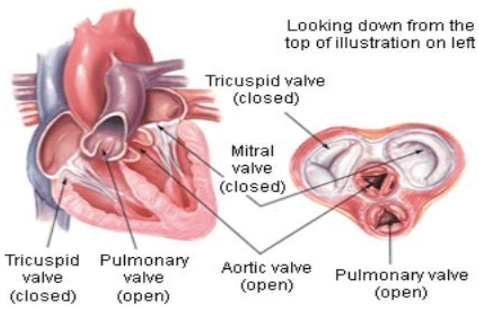

Figure 4: 4 valve mechanism motion during systole (ventricles contracting) [8]

During systole process, 4 valves will be involved to do open and close motion as shown in figure 4. A ventricle contracting motion is carried out with close mitral and tricuspid valve to pump blood flow from atria to ventricles. Base on the understanding of mechanism motion of 4 valve involved during systole and diastole process, ECG data will be very useful to help with log in synchronously with SCG data to specify each specific valve due to data of ECG able to show the S1 and S2 phase which stand for systole and diastole process timing.

2.1 Signal Processing

Upon finish collecting all the necessary data, acceleration data needed to be converted into frequency of vibration which contains information related to mechanical motion of heart [9]. The minimum requirement of output resolution accelerometer to collect SCG signal is 12 bits and to prove the SCG signal is the source of cardiac signal, most researcher like [3,7,10] uses ECG measurement to compare with their own result. Before processing the signal collected, a band pass filter with cut off frequency band that remove the noise frequency such as white noise, signal offset or trend must be used. ECG independent based method to detect heart beat from SCG signal introduced by [4] who used Hilbert adaptive beat identification technique (HABIT) algorithm to detect heartbeats and calculate beat-to-beat intervals. They took sum of the acceleration from different axes (x-, y- & z-axes) and fed it into the Hilbert transform to extract the heat pulse waves. Hilbert transform has been introduced by [11,12] for detecting the QRS complexes in ECG signal but it also possessed the capability of locating heartbeats in seismocardiogram signals.

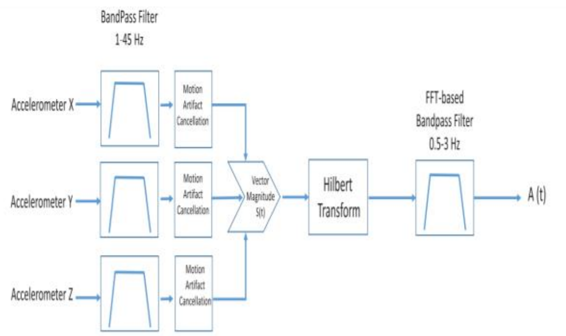

Figure 5: Block diagram of signal processing with using Hilbert transform algorithm [4]

At the end of signal processing with Hilbert transform algorithm shown in figure 5, the output is enveloped of SCG signal, A(t), which will be integrated into a very low-frequency approximation of the seismocardiogram velocity signal, also known as the principal signal. Due to integration smooth the signal A(t), the local maxima in the A(t) means the peak of the amplitude SCG signal have some latency and inaccuracy in position compared to integration before of the original SCG signal. Thus, they did a refinement process to localize heartbeat in SCG with using adaptive thresholding method which inspired by [13]. After the refinement process, they calculated the difference between the total number of S1-S1+ interval from SCG signal and the total number of R-R intervals from ECG to get the root means square error (RMSE). From their result shown that this method is quite accurate, and this method proved that without using ECG fiducial points to operate also able to detect the heartbeat by using SCG heartbeat detector only.

3. Simulation and Results

With the result of using tri-axial accelerometer to collect SCG signal and synchronized with ECG signal, both data collected will be filtered using fast Fourier transform (FFT) algorithm to remove noise signal.

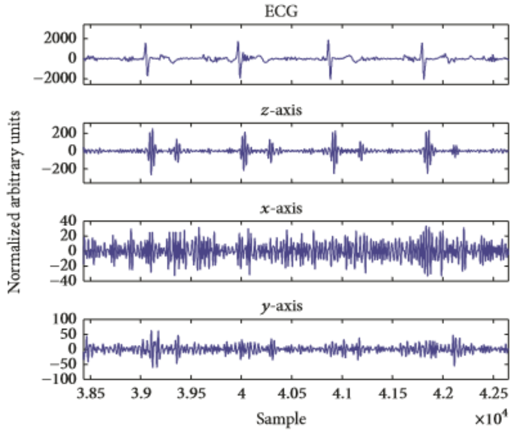

Figure 6: Result of tri-axial acceleration signal and ECG signal [3]

As can be seen from this figure 6, location of z-axis peaks is much closer to the R peak of QRS complex compared other location of x and y-axis. The reason is z-axis is coaxial with the lung movement and the heart.

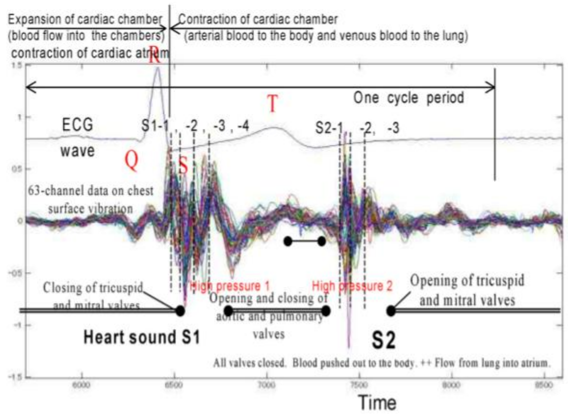

Figure 7: SCG signal compared with ECG signal [6]

The sharper amplitudes and upper frequency (>5Hz) contents is the result of pulsation of the chest wall due mainly to acoustic waves produced by the heart valves as reported by [14]. Figure 7 is the result of single accelerometer output signal which compared with ECG signal to show the systole and diastole acceleration in time domain. Through this result visualized by frame-by-frame advance showed a typical heart motion of the strong pressure shock due to closing tricuspid valve and mitral valve (Sl), and the closing aortic valve and pulmonic valve (S2) in sequence.

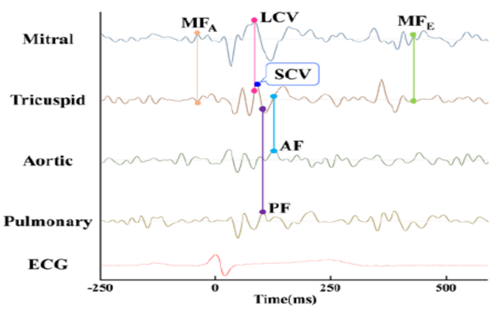

Figure 8. Synchronous several feature points from SCG spectrum to match with ECG signals [6]

Figure 8 is one of the example outputs from multi-channel of SCG spectrum to show the mechanical activity of each specific location like mitral, tricuspid, aortic and pulmonary valve. There got six new feature points identified through multi-channel of SCG spectrum in Table 1.

Table 1: Feature points identified through multi-channel of SCG spectrum

Feature points	Identified location
Left ventricular lateral wall contraction peak velocity (LCV)	Mitral valve
Septal wall contraction peak velocity (SCV)	Tricuspid valve
Trans-aortic valvular peak flow (AF)	Aortic valve
Transpulmonary peak flow (PF)	Pulmonary valve
Trans-mitral ventricular relaxation peak flow (MF_E) and Trans-mitral atrial contraction peak flow (MF_A)	Mitral valve

Those feature points are the signal of mechanism motion occurred by each valve. These feature point also can be used to represent the duration of each valve open and close to differentiate cardiac cycle whether is in normal or abnormal pace.

3.1 Cardiological Data Analysis

In order to analyze the data of SCG for getting those feature point, a method of simultaneous for the data acquisition on SCG and ECG signal was introduced by Prasan Kurmar mentioned in [15]. The ECG and SCG cardiac signal bring the information of cardiac electrical and mechanical activities respectively. They aligned these SCG waveform together with ECG waveform as shown in figure 7.

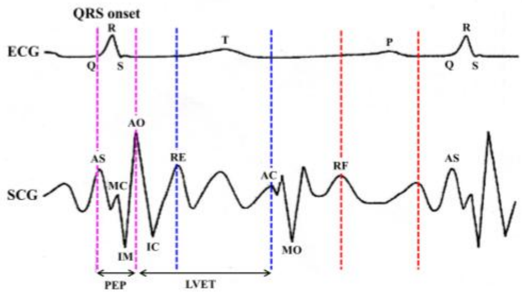

Figure 9: Cardiac electrical and mechanical activities. [15]

ECG waveform can bring the data of QRS complex which corresponding to cardiac electrical activities. QRS complex can be the reference for SCG data to extract those feature point. Example shown in figure 9, the ventricle depolarization, a cardiac electrical activity that takes place during the QRS complex can be represented by the corresponding cardiac mechanical activities that take place between atrial systole, AS to the opening of aortic valve, AO. Similarly, during the ventricle re-polarization (T wave) of ECG, the cardiac mechanical activity such as rapid ejection of blood flow RE takes place until the closing of aortic valve AC. Finally, during the atrial depolarization represented as P wave, cardiac mechanical activity known as rapid diastolic filling RF can be observed.

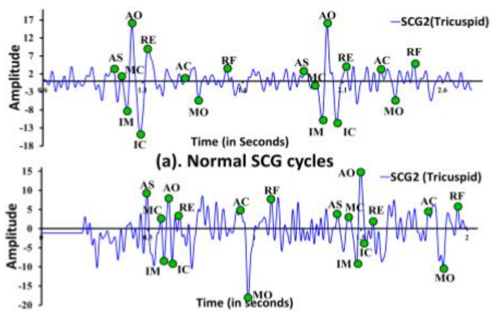

Figure 10: Feature point delineation in (a) normal SCG cycles; (b) abnormal SCG cycles. [15]

To differentiate normal and abnormal SCG cycles, feature point delineation mechanism is proposed in [15]. SCG raw data as input and measured along with ECG to monitor and ascertain the cardiac abnormalities with improved reliability. Data output from SCG is those 9 feature points reveal various cardiac mechanical activities such as peak of atrial systole AS, closing of mitral valve MC, isovolumic movement IM, opening of aortic valve AO, isovolumic contraction IC, peak of rapid systolic ejection RE, closing of aortic valve AC, opening of mitral valve MO and peak of rapid diastolic filling RF. Based on the previous studies about information get from SCG signal is able to estimate hemodynamic parameters [16,17].
The following features extracted as shown in figure 9: Isovolumic contraction time (MC-AO) and its slope, systolic ejection time (AO-AC), isovolumic relaxation time (AC-MO), the area under curve during rapid systolic ejection (RE), the maximum of rapid ejection and the slope of its increase, the time between the ECG R wave and the opening of mitral valve.

4. Conclusion

The experiment done with accelerometer sensor array only focus on the chest surface where to detect heartbeat vibration to differentiate whether function or dysfunction exist in cardiac cycle. In fact, heart disease not only cause by the dysfunction in cardiac cycle but also can affected by blood vessel blockage where is outside the cardiac location. In future, should using accelerometer detect the smoothness of the blood flow by attaching it on position of arm which able to get more the information help in diagnose heart disease.

Acknowledgement

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