6

Assessment of Electro-mechanical Window using the Wearable Patch Based on SCG System

In this chapter, use of Seismocardiography is explored to assess the E-M window. The E-M window is defined as the duration between the electrical systole (QT) and the mechanical systole (QS2). Traditional methods for the estimation of the electrical systole and the mechanical systole are ECG and PCG. As discussed in Chapter 2, PCG needs to improvise in terms of its size and weight, to make it convenient to wear for long-term. Further, the PCG signal is susceptible to various noises, which limits its use in the clinical environment. As a result of the aforementioned superiority of SCG system, a novel system to estimate the E-M window is explored in this chapter that replaces PCG by the SCG.

6.1 INTRODUCTION

The E-M window is defined as the duration between the electrical systole (QT) and the mechanical systole (QS2). The Q and T points represent the cardiac events in electrical activity of the heart, and S2 is the second fundamental component of the heart sound signal In several studies, the E-M window is also interpreted as the ratio between QT and QS2 (QT/QS2) [De Caprio et al., 1984; Ferro et al., 1986]. In healthy individuals, the QT duration is shorter than the QS2 duration [Guns et al., 2012; Kim et al., 1984].

The E-M window provides early risk indicators for several cardiovascular diseases [Curtis and Jr, 2002]. Furthermore, it is a robust parameter that is minimally affected by changes in heart rate or body temperature [Van Der Linde et al., 2008]. The E-M window has the shown prognostic relevance in patients with coronary artery diseases [McKay et al., 1999]. It also represents a reliable and sensitive index of autonomic tone change [De Caprio et al., 1984; Caprio et al., 1986], which is a risk indicator of sever ventricular arrhythmia and sudden death [Curtis and Jr, 2002]. The E-M window also has been demonstrated as a risk indicator for death in patients with previous myocardial infarction [Ferro et al., 1986; Cuomo et al., 1988]. In the study of P. J. Guns et. al. on the anaesthetized guinea pigs, the QT/QS2 has been identified a sensitive marker for the detection of Tosade de Pointes (TdP) [Guns et al., 2012]. TdP is highly associated with delayed ventricular repolarization and sudden cardiac death.

The E-M window is estimated by obtaining the Q and T wave, in ECG, and second heart sound (S2), in PCG, as shown in Figure 6.1. The ECG and the PCG are widely used techniques because of their ease to use and portability features [Jain and Tiwari, 2014]. However, PCG needs improvisation in terms of the size and weight of its sensor, stethoscope. The small size and low weight are in favour of the convenience of the subject while long-term monitoring. Long-term monitoring of the heart is expected to provide an early diagnostic marker of the heart diseases [Medtronic, 2012]. Furthermore, the vulnerability of the PCG to environmental noises limits its use in the clinical environment only. Henceforth, a robust sensor is required, which should also be small in size and low in weight.

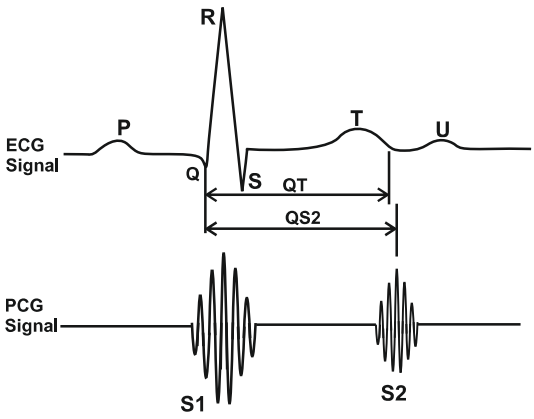

Figure 6.1 : Measurement of E-M window

In view of the above shortcomings of the PCG, in this chapter, we proposed a new technique to obtain E-M window using SCG in replacement to the PCG. SCG uses a sensor called accelerometer to measure the precordial-vibrations from the chest wall [Jain and Tiwari, 2014; Akhbardeh et al., 2009]. As discussed in Chapter 1, due to small size and low weight of the accelerometer, SCG is convenient to wear. Further, SCG does not require a microphone, which is required in the PCG to convert sound signal into an electrical signal. Thus, the SCG signal is robust to environmental noises. We estimated the E-M window using SCG and ECG and compared it to the estimated E-M window using PCG and ECG. For this purpose, ECG, PCG and SCG signals are recorded of 10 subjects.

The rest of the chapter is organised as follows; In Section 6.2, the proposed system setup, details about data acquisition, and signal processing used to estimate the E-M window are described. Results and discussion about obtained diagnostic parameters are discussed in Section 6.3. At last, in Section 6.4, the conclusions are discussed.

6.2 METHODOLOGY

The proposed system setup using ECG and SCG to assess the E-M window is described as follows.

6.2.1 System Setup

A system is presented to acquire ECG and SCG signals simultaneously, as shown in Figure 6.2. The two electrodes for the ECG signal acquisition and the accelerometer for the SCG signal acquisition were placed near to the sternum and V3 lead position. Such type of arrangement of sensors makes a straight patch, which is in favour of the convenience of the subject to wear. The amplitude of both the acquired signals ranges from 0-5 Volts. Henceforth, both signals are fed directly to the PC through the 3.5 mm audio input jack (sound card). The fed signals to the PC are converted from analog form into digital form using the inbuilt ADC of the PC. The sampling rate for the conversion was set to 1K Hz, which is adequate because components of all three signals lie below the frequency 500 Hz [Jain and Tiwari, 2014]. Hence the system setup is easy to operate and low cost as it does not require external data acquisition device.

6.2.2 Data Acquisition

For the proposed study, the SCG, ECG and PCG signals were acquired with the following details.

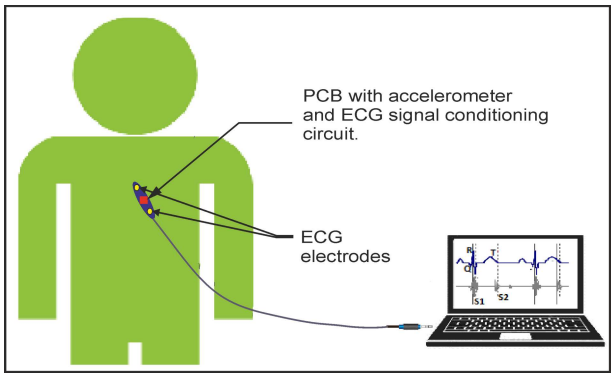

Figure 6.2 : The proposed system setup

(a) SCG Signal Acquisition

For SCG signal, the accelerometer was placed above the xiphoid process and left to the sternum, as shown in Figure 6.3. This position was chosen because second heart sound, which is important for the analysis of the E-M window, is pronounced more on the left side of the chest compared to the sternum [Pandia et al., 2012]. A three-axis micro-machined accelerometer (MMA7361L, Freescale semiconductor) is used. It has on-board signal conditioning and filtering circuit, which attenuates frequency contents beyond the 400 Hz. It has a sensitivity level of 800 mV/g, where g is the acceleration due to the gravity of the Earth [semiconductor, 2011]. Among the three axes of it, the signal only from the z-axis, perpendicular to the chest, is acquired. It is because the heart pushes, felt at the chest wall, are strongest in the direction perpendicular to the chest. The acquired signal is fed to the PC through the audio jack input. Power to the accelerometer is provided through a portable paper-battery.

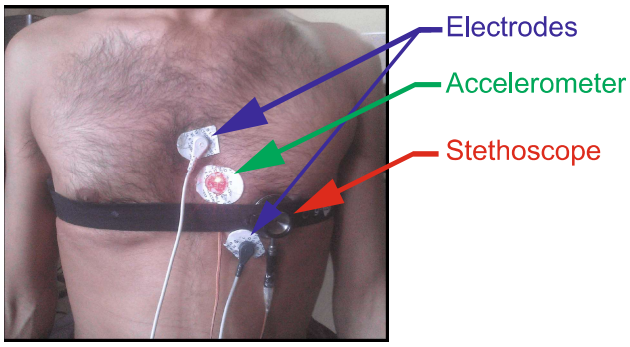

Figure 6.3 : System setup for signal acquisition using (a) PCG, (b) SCG and (c) ECG

(b) ECG signal acquisition

Q and T wave are most visible in the V3 lead among all 12 leads of the ECG. Henceforth, only single lead (V3) ECG is recorded. To measure the lead V3 ECG signal, two electrodes were attached in a row, as shown in Figure 6.3. Typically, the acquired ECG signal is low in amplitude and get affected due to various noises such as power line interference, baseline wandering. For the amplification and filtering of the acquired ECG signal, an Application-Specific Integrated Circuit (ASIC) AD8232 (Analog Devices), is used. The AD8232 consists of a signal conditioning block for ECG [Analog-Devices].

(c) PCG signal acquisition

PCG signal is acquired using a stethoscope placed close to the apex, as shown in Figure 6.3. It was strapped firmly to the chest with the help of a belt. The acquired sound signal is converted into an electrical form using an electret condenser microphone. Then, the output of the microphone is fed to the PC through 3.5 mm audio input jack. The acquired signals for 10 seconds duration are shown in Figure 6.4.

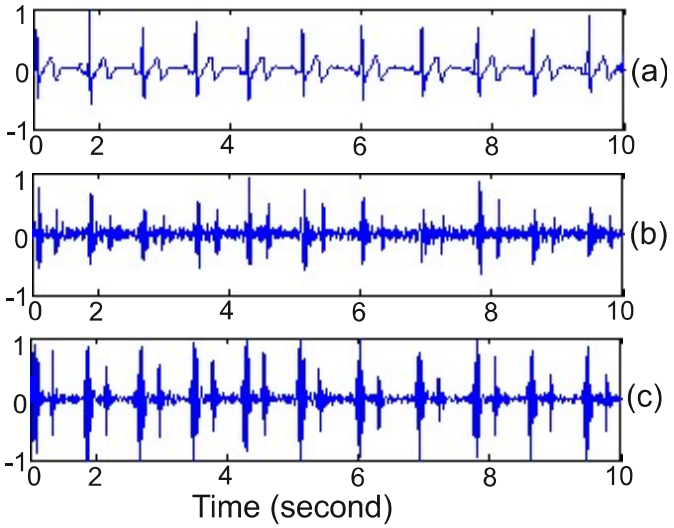

Figure 6.4 : The acquired signals (a) ECG, (b) SCG, and (c) PCG

6.2.3 Signal Processing

As discussed previously, for the estimation of the E-M window, Q and T waves from the ECG signal and S2 from the heart sound signal have to be identified. Henceforth, the acquired signals are processed in MATLAB® (MathWorks) to detect these waves automatically. Although signals were recorded in a clinical environment, these signals need to be filtered to suppress the unwanted components from the acquired signals. The acquired ECG signal is filtered using a band-pass filter having its frequency band from 1-40 Hz. For the PCG and the SCG signals, a band-pass filter is constructed with frequency band from 10-60 Hz.

After filtering, the signals are processed to detect the desired waves. To detect Q and T wave, first the R wave is detected in the ECG signal. The R wave has a larger amplitude than other waves and hence simple to detect. Then, Q wave is detected by detecting negative to positive deflection before the R wave. The T wave is detected as zero crossing point in a window with length 400 ms and starting point at R wave.

For the detection of S2 from the PCG and the SCG signals, the envelope of both the signals were extracted using normalised average Shannon energy [Choi and Jiang, 2008]. After the envelope extraction, peaks are detected by applying a threshold to the envelopes. The threshold is obtained using Otsu's threshold method [Otsu, 1979], which selects a threshold such that the intra-class variance will be minimized. Then, the peaks are identified as S1 and S2 based on the energy of the particular peak. A graphical user interface is also developed for the estimation of E-M window using the MATLAB ® software, as shown in Figure 6.5.

6.3 RESULTS AND DISCUSSION

In this chapter, for experimental work, ECG, PCG and SCG signals are recorded of 10 young and healthy volunteers for one-minute duration. The participated volunteers have

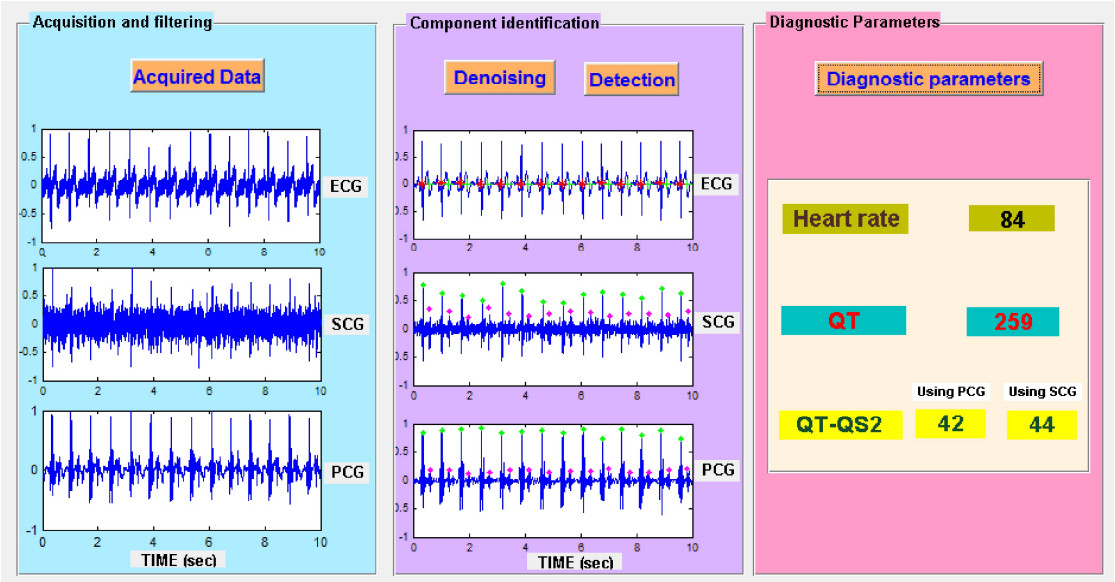

Figure 6.5 : The graphical user interface for the estimation of E-M window

a mean age of 25 years and mean weight of 69 Kilograms. The experimental procedures involving human subjects described in this chapter were approved by the Institutional Review Board.

Diagnostic parameters such as the heart rate, the QT interval and the E-M window using PCG and SCG signals are obtained. The mean values of these obtained parameters over one-minute duration are provided in Table 6.1, for ten subjects. From the table, it can be observed that the lowest heart rate is 61 and the highest heart rate is 85. The QT interval is lowest (270) for the subject with highest heart rate and it is maximum for the subject with the lowest heart rate. Thus, it demonstrates the relationship between the heart rate and QT interval. For the analysis of the E-M window, both the QT to QS2 duration and the QT/QS2 ratio are provided in Table 6.1. From the table, it can be observed that the QS2-QT is positive for all subjects and the QT/QS2 ratio is less than one. As discussed previously, these observations indicate that the participated volunteers were healthy with no cardiovascular diseases.

To demonstrate the relation between the estimated E-M window using the existing method PCG and the proposed method SCG, Bland-Altman's plots for both QS2-QT duration and QT/QS2 ratio are obtained and plotted in Figure 6.6(a) and Figure 6.6(b), respectively. Bland-Altman's plot is a statistical method used to assess the relative agreement between two measurements, measured on the same scale [Bland and Altman, 1999]. In this graphical method, the difference between the measurements of two techniques (x1-x2) is plotted against the average (x1+x2)/2 of them. In addition, reference lines such as the mean bias line, 95% upper ($1.96 \times Standard\_Deviation$), and 95% lower ($-1.96 \times Standard\_Deviation$) lines are also overlaid on the same scatter plot. Using this method, it can be determined whether these two methods can be used interchangeably or the new method can replace the established measurement.

From the Figure 6.6(a) and Figure 6.6(b), it can be observed that the obtained results for the proposed method are in agreement with 95% confidence to the existing method.

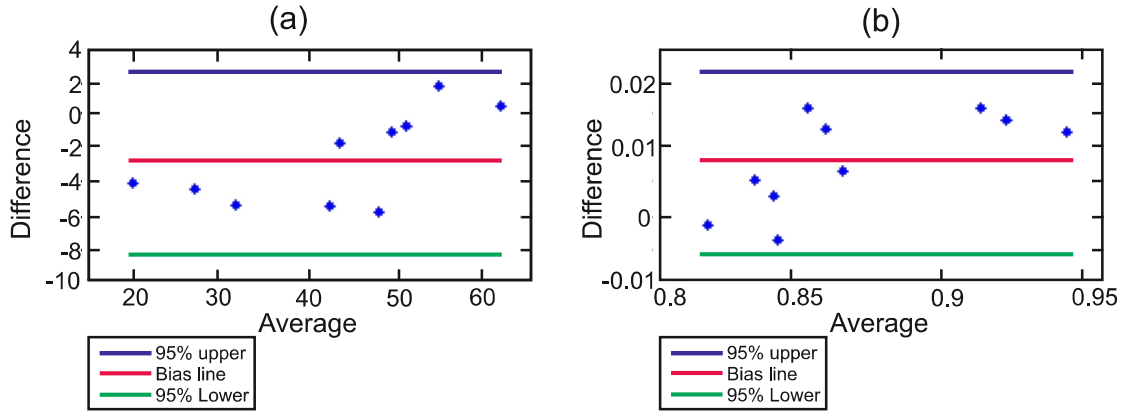

Figure 6.6 : Bland Altman plot between the SCG and the PCG: (a) to measure QS2-QT duration and (b)to measure QT/QS2 ratio

Table 6.1 : Obtained diagnostic parameters for 10 subjects

	HR	QT	PCG		SCG	
		(ms)	QS2-QT	QT/QS2	QS2-QT	QT/QS2
Subject 1	76	298	43.5	0.872	45.4	0.867
Subject 2	73	251	49.2	0.835	50.3	0.832
Subject 3	61	331	30.8	0.914	36.2	0.900
Subject 4	81	280	40.3	0.870	45.9	0.859
Subject 5	73	282	63.1	0.817	62.4	0.819
Subject 6	80	311	17.1	0.946	21.4	0.935
Subject 7	73	301	46.0	0.866	51.7	0.852
Subject 8	75	297	25.1	0.921	29.7	0.908
Subject 9	74	294	55.9	0.839	54.2	0.844
Subject 10	85	270	50.4	0.841	51.3	0.840

6.4 CONCLUSIONS

In this chapter, we proposed a new system for the estimation of the E-M window using ECG and SCG. The system is convenient to wear due to the small size and low weight of the SCG sensor, accelerometer, and due to the placement of the sensors. For the experiment, the E-M window is estimated for ten healthy subjects. The obtained results show that the SCG can be a suitable alternative to the PCG. The SCG has superiority over PCG in terms of robustness to various noises and dimensional features of its sensor. However, the accuracy of the SCG has to be analysed in different groups of people having obesity, and cardiovascular diseases.

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