Automatic Estimation of Cardiac Time Intervals using Combined SCG and ECG

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Introduction

Seismocardiographic signal (SCG) is the chest vibration induced during the cardiac cycle due to cardiac muscle contraction, cardiac valves movement and blood momentum changes [1-5]. SCG can be used for estimating cardiac time intervals (CTI), which has been shown to be of potential value in predicting certain heart diseases [7, 8]. Detecting CTI relies on accurate annotation of SCG and electrocardiogram (ECG) fiducial points including aortic valve opening (AO) and closure (AC), mitral valve opening (MO) and closure (MC) and ECG Q, R and T peaks [3, 9]. Several studies addressed fiducial points detection using different methods [3, 9-11], however, a fully automated method that is simple and accurate is not yet available. Therefore, the objective of the current study is to introduce such a method and validate it by comparing the extracted CTI to the literature and highlight discrepancies in reporting CTI. The focus will be on the MC and AC events in SCG which are associated with the first and second heart sounds respectively [13].

Methods

SCG and ECG were simultaneously acquired from 10 healthy subjects (5 females, Age: Mean±SD = 19.8±1.03 years) during normal breathing for one minute at a sampling frequency of 10 kHz. The subjects laid supine, with their back inclined at 45° and legs extended horizontally. SCG was acquired using an accelerometer affixed to the skin over the fourth intercostal space near the left sternal border using double-sided medical grade tape. ECG and SCG were bandpass filtered with passbands of 0.5-50 and 0.5-150 Hz, respectively. These bands ensured removing high frequency noise like speech and low frequency noise like motion artifacts and breathing. In addition to ECG and SCG, audible SCG was extracted by applying a high pass filter to SCG at 20 Hz, which will help in the annotation process. ECG R peaks were identified using Pan-Tompkins algorithm [14]. Then, SCG, ECG and audible SCG were segmented into beats such that each beat starts 250 ms before the timing of the ECG R peak. The total number of segmented beats was 764 beats; all were annotated to detect MC, AC, and ECG Q and T waves.

The Q wave was defined as the first point before the R peak at which the ECG slope (i.e., first time derivative) approached zero. The T wave peak was defined as the maximum of the ECG inside a 200 ms window starting 125 ms after the R peak. The T wave end was defined as the point (after the T wave peak) at which the ECG slope approached zero. MC was defined as the first positive peak in SCG, after the ECG R peak timing, [3] at which the SCG amplitude had to be greater than a threshold of 20% of SCG peak-to-peak amplitude between the R wave and the T wave peak timings. AC is a sharp wave in SCG that happens near the end of the ECG T wave [3, 15]. It was defined as the first positive peak in the audible SCG after the T wave peak timing at which the audible SCG amplitude had to be greater than a threshold of 30% of the audible SCG peak-to-peak amplitude between the T wave peak timing and the end of the beat. The CTI calculated, to validate the proposed annotation method, are Q-T_{end}, R-MC, and R-AC. All the automatically annotated beats were manually annotated to assess the accuracy of the proposed automatic method.

Results and Discussion

Figure 1 shows an example of the beats and the annotated Q, R, T_{peak}, T_{end}, MC, and AC. In Figure 1, the ECG and SCG of the shown beat were normalized by removing the mean and dividing by the standard

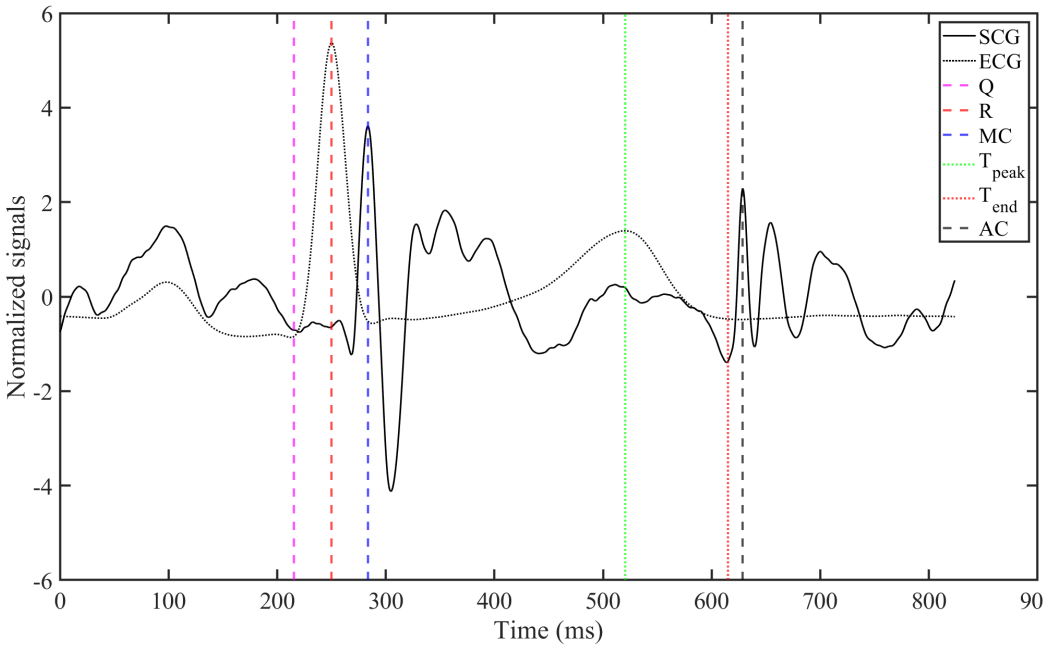

Figure 1. Example of the annotated beats represented by SCG and ECG and the detected fiducial points

deviation of each signal. Table 1 shows the extracted CTI compared to the literature. The current study results are consistent with the literature although different values [11] were also reported. Compared to manual annotation, the proposed automatic annotation was able to detect all the addressed fiducial points correctly except for 9 beats in one subject where the threshold of AC amplitude had to be reduced to 20% instead of 30% to detect AC correctly.

CONCLUSIONS

The current study presented a simple accurate (as far as the current healthy age group is concerned) automated method to detect MC, AC, Q, and T peak and end. Q-T_{end}, R-MC and R-AC time intervals were calculated and compared to the literature. This is expected to leverage the clinical utility and commercial viability of SCG especially when combined with ECG to extract hemodynamic parameters. The small and homogeneous study cohort in the current study limits its generalizability. Therefore, future work will aim to analyze more subjects, extract more fiducial points and test the effect of different factors (e.g., age, sex, pathology, etc.) on CTI. This will require understanding the physiological implications of the addressed pathology on cardiac dynamics and its reflection on SCG morphology. The effect of the pathology can be continuous or intermittent. Regarding artifacts, it is very important to ensure the quality of the acquired signals. The beats acquired in the current study were clean (i.e., low noise levels). One of the factors that should be considered carefully is the accelerometer location as it affects SCG morphology [16]. As such, future work might recommend different locations to collect clean signals for different pathologies.

Table 1. Mean and standard deviation of the extracted CTI compared to the literature.

CTI	Current study	Literature
Q-T_{end}	382±28 (ms)	200-400 (ms) [6]
R-MC	41±9 (ms)	43.9±11.4 (ms) [12]
R-AC	349±26 (ms)	348±37 (ms) [11]

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Introcution

- Seismocardiography (SCG) is cardiac-induced chest wall vibration that is often measured non-invasively by accelerometers.
- SCG is thought to be related to myocardial contractions, valve closures and changes in blood momentum during the cardiac cycle.
- SCG can be used to estimate cardiac time intervals.
- Detecting CTI relies on accurate annotation of SCG and electrocardiogram (ECG) fiducial points including aortic valve opening (AO) and closure (AC), mitral valve opening (MO) and closure (MC) and ECG Q, R and T peaks
- A fully automated annotation method that is simple and accurate is not yet available.

Objectives

- Introduce a simple automated annotation method for SCG and ECG and validate it by comparing the extracted CTI to the.

Methodology

- SCG and ECG were simultaneously acquired from 10 healthy subjects (5 females, Age: Mean±SD = 19.8±1.03 years) during normal breathing for one minute at a sampling frequency of 10 kHz.
- The subjects laid supine, with their back inclined at 45 degrees and legs extended horizontally.
- SCG was acquired using an accelerometer affixed to the skin over the fourth intercostal space near the left sternal border using double-sided medical grade tape.
- ECG and SCG were bandpass filtered.
- Audible SCG was extracted by applying a high pass filter to SCG at 20 Hz.
- SCG, ECG and audible SCG were segmented into beats based on the ECG R peak.
- The total number of segmented beats was 764 beats; all were annotated to detect MC, AC, and ECG Q and T waves.

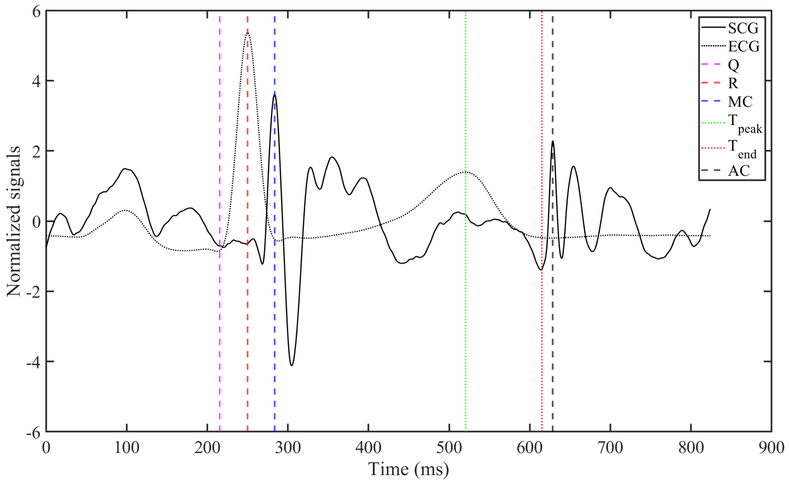

Figure 1. Example of the annotated beats represented by SCG and ECG

Results

Table 1. Mean and standard deviation of the extracted CTI compared to the literature.

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- Table 1 shows the extracted CTI compared to the literature.
- The current study results are consistent with the literature.
- All beats were manually annotated and compared to the automatic annotation method.
- The proposed automatic annotation was able to detect the addressed fiducial points correctly except for 9 beats in one subject where the the threshold of AC had to be reduced to 20% instead of 30% to detect AC correctly.

Conclusions

- The current study presented a simple accurate (as far as the current healthy age group is concerned) automated method to detect MC, AC, Q, and T peak and end.
- Q-Tend, R-MC and R-AC time intervals were calculated and compared to the literature.
- This is expected to leverage the clinical utility and commercial viability of SCG especially when combined with ECG to extract hemodynamic parameters.
- The small and homogeneous study cohort in the current study limits its generalizability.
- Therefore, future work will aim to analyze more subjects, extract more fiducial points and test the effect of different factors (e.g., age, sex, pathology, etc.) on CTI.
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- As such, future work might recommend different locations to collect clean signals for different pathologies.

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