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Signal Averaging with Heartbeat Envelope for Non-Contact Heart Sound Measurement

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Summary:
We propose a non-contact heart sound measurement method using signal averaging in conjunction with the heartbeat envelope as a trigger. The performance of the heartbeat envelope was 0.01 s as the standard deviation of the R-R interval estimation error, meeting the trigger requirement for our signal averaging method. The main component of the heart sound was extracted from a sound signal measured 40 mm away from the chest wall.

Keywords: heart sound, non-contact measurement, signal averaging, heartbeat, microphone

Introduction

Cardiovascular disease (CVD) is the most common causes of death worldwide [1]. Heart sound monitoring is a popular approach to early detection of these diseases. There have been many studies to measure heart sounds using wearable devices [2]. However, these devices are not yet widely used in the world. One of the reasons for this is that these wearable devices have disadvantages such as discomfort due to constant wear and the need for intermittent charging. Therefore, a non-invasive and user-friendly heart sound monitoring method is desirable.

Previously, we have attempted to measure heart sound without contact [3,4]. In particular, we have proposed an approach using signal averaging, and reported that signal averaging with an appropriate trigger, e.g., an electrocardiogram (ECG), can extract the heart sound from the non-contact measured sound [4]. However, because ECG measurement requires contact, a method is required to acquire the appropriate trigger without contact.

In this study, we propose to use the heartbeat envelope instead of the ECG as the trigger, and the performance of this trigger is clarified.

Materials and Methods

The outline of our method is illustrated in Fig. 1. Heart sound is extracted from a non-contact measured sound through signal averaging using heartbeat envelope as the trigger. The heartbeat envelope is the power variability of the heart sound and was extracted from non-contact measured sound using independent component analysis (2-ch), full-wave rectification, and low-pass filtering (5 Hz, 1st order, Butterworth).

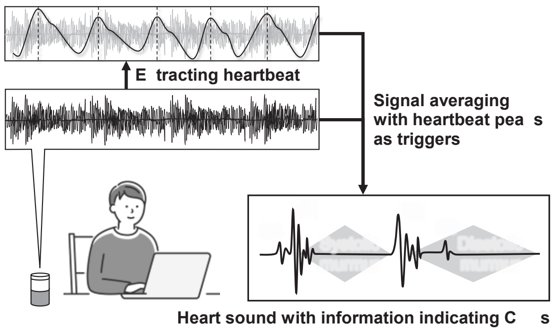

Fig. 1. Outline of our signal averaging method for non-contact heart sound measurement.

The sound was measured using two sets of a microphone and preamplifier (MI-1235 and IM-3111, Ono Sokki Co., Ltd.) in a quiet conference room. The front of the microphone was positioned at a distance of 40 mm from the chest wall. The measurement duration was 180 seconds. During the measurement, the subject (the first author) was shirtless, sat motionless in a chair, and breathed slowly. The sampling frequency and quantization resolution are 48 kHz and 16 bits, respectively. The measured sound was pre-processed using a bandpass filter (10 Hz to 1000 Hz, 1st order Butterworth) to extract the frequency range of the heart sound.

ECG readings were acquired simultaneously with the heart sound to use as a reference for the appropriate trigger. It was measured using a 3-point induction method with an ECG monitor (AD8232 SparkFun Single Lead Heart Rate Monitor, SparkFun Electronics).

Results and Discussion

Figure 2 shows an example of the synchronized ECG and the heartbeat envelope. This indicates that the heartbeat envelope was successfully extracted to sufficiently detect the peaks. Specifically, the peaks of the ECG and the heartbeat appear alternately, and there are near-constant delays between the two of approx. 64 ms.

Figure 3 shows the error of the R-R interval (RRI) estimated by the heartbeat, compared to the reference RRI. The mean ± standard deviation is – 0.0004 ± 0.01 s. This value meets the trigger accuracy (below 0.04 s [4]) for our signal averaging method. On the other hand, the errors are in three clusters. This is because the envelope consists of two small peaks instead of one. We believe that this variance can be reduced by using cross-correlation functions.

Figure 4 (a) shows the raw sound. This represents the difficulty of non-contact heart sound measurement due to the low power of the heart sound. Figure 4 (b) shows the sound extracted by the signal averaging with the ECG trigger. The number of detected peaks was 220. This sound has both S1 and S2, which are the main components of the heart sound. It indicates that signal averaging with an appropriate trigger is effective for non-contact heart sound measurement. Figure 4 (c) shows the sound extracted by signal averaging with the heartbeat envelope trigger. The number of detected peaks was 207. The resulting sound has S1, which means that the heartbeat envelope trigger works properly. In other words, this demonstrates the feasibility of complete non-contact heart sound measurement. On the other hand, the waveform remains noisy even from a distance as short as 40 mm. Therefore, the proposed method shows promise in non-contact heart sound monitoring. However, further improvements are necessary.

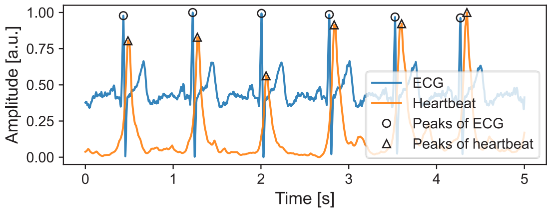

Fig. 2. Synchronized ECG and heartbeat envelope. Circles and triangles represent detected peaks.

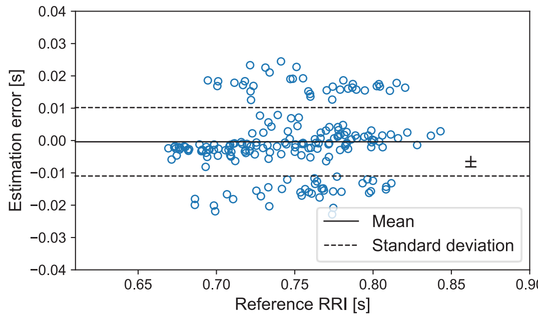

Fig. 3. Error of RRI estimated by the heartbeat envelope, against the reference RRI.

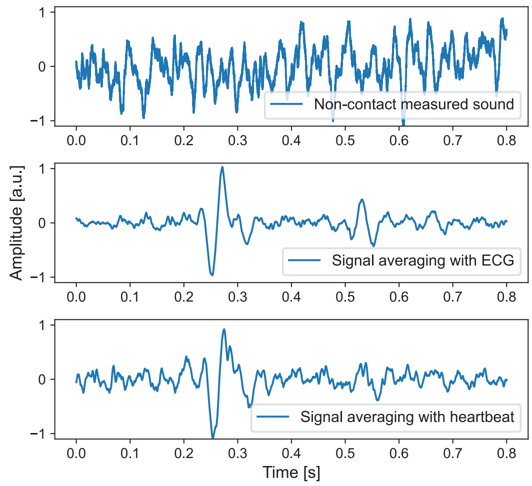

Fig. 4. (a) Raw sound. (b) Output using the ECG trigger. (c) Output using the heartbeat envelope trigger.

Conclusion

We proposed using heartbeat envelope instead of ECG as the trigger for our non-contact signal averaging heart sound measurement method. The trigger accuracy of the heartbeat envelope was 0.01 s as a standard deviation of the RRI estimation error. This value met the requirement of our signal averaging method. This method demonstrated that the S1 can be extracted from the sound measured 40 mm away from the chest wall. The next step is to improve signal noise and extend the measurement distance.

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