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Simultaneous measurement of respiration and heart rate using airborne ultrasound
空中超音波を用いた呼吸・心拍の同時計測

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1. Introduction

Acoustic sensing in air has the potential to obtain various information about a surrounding object such as its position, shape, material and movement. In previous paper, we have examined the reflection characteristic of human body [1], and proposed a noncontact measurement technique of human surface velocity to obtain vital information using airborne ultrasound [2]. We also measured body - surface velocities by breathing and heartbeat using proposed method when the volunteer was breathing and holding the breath, respectively [3].

In this paper, we present results of simultaneous measurement of respiration and heart rate when the volunteer was breathing in the supine position without clothes.

2. Experiment

2. 1 Measurement configuration

Body surface velocity is measured by analyzing the reflected signal from the body. **Figure 1** shows measurement configuration. The speaker and the microphone were located above the volunteer breathing and lying on a bed. Signals were transmitted from speaker and reflected signals from the body was received by the microphone. We showed the breathing period of 4 s to the volunteer with the movie. The laser Doppler vibrometer (LDV) was used as the reference to compare measurement results of body-surface velocities using ultrasound. The contact-type cardiac sensor was also attached to the neck of the volunteer as the reference of heart rate.

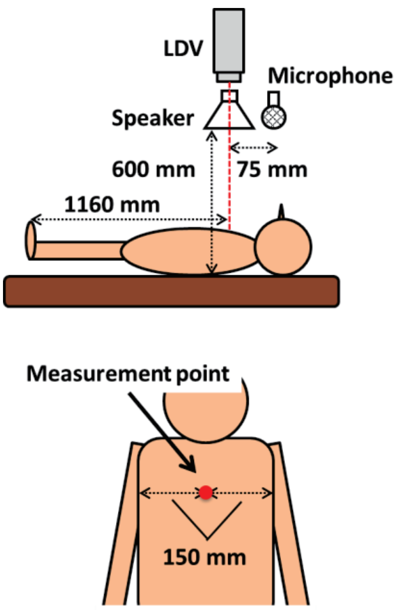

Fig. 1 Measurement configuration in the supine position.

2. 2 Measurement system

When body-surface moves, propagating time of signal also changes. In this system, body-surface velocity was estimated by using propagating time difference.

To improve signal-to-noise ratio (SNR), the 8th-order M-sequence-modulated signal centered at 40 kHz was used for the transmitted signal. The SNR of received signals is increased by pulse compression. The amount of SNR improvement using 8th-order M-sequence-modulated signal is 24 dB. Transmission and receiving of signals were repeated at intervals of 50 ms for 60 s.

After processing by pulse compression, using *i*th and (*i*+1) th signal, $a_i(t)$ and $a_{i+1}(t)$, phase difference was calculated by $\arg\left(a_{i+1}(t)\right) - \arg\left(a_i(t)\right)$. Body-surface velocity was estimated by tracking phase difference. Measurement using phase difference is expected to have higher resolution than using time of flight of maximum peak.

2. 3 Results

Figure 2 (a) shows received signals. Reflected signals from body surface can be seen at 2.7 ms. **Figure 2 (b)** shows 2-D plot of phase difference. Changes of phase difference can be seen at the time of flight of reflected signals. **Figure 3** shows measured body-surface velocities that are calculated using phase difference and measurement result of LDV. Comparing measurement results using ultrasound and LDV, waveforms of each measured velocities were coincident. As a result, body-surface velocity could be measured properly by the proposed method using ultrasound.

To improve SNRs of measured velocities, passband filters in frequency domain were used. The Tukey window function, whose passband is from 0 to 0.5 Hz (Filter 1), was used for the measurement of breathing, and the Tukey window function, whose passband is from 0.8 to 2.5 Hz (Filter 2), was used for the measurement of heartbeat. **Figure 4** shows measured body-surface velocities using Filter 1. Body-surface velocities by breathing become clear.

Figure 5 shows measured body-surface velocities using Filter 2 and measurement result of the cardiac sensor. As shown in **Fig. 5 (a)**, periodic velocities approximately ± 1 mm/s could be separated. Comparing **Fig. 5 (a)** and **(b)**, periods of velocity and heartbeat were coincident. Therefore, it is found that velocities as shown in **Fig. 5 (a)** is caused by heartbeat. As a result, body-surface velocity by breathing and heartbeat of breathing volunteer could be measured simultaneously.

3. Conclusion

We tried to measure body-surface velocities by breathing and heartbeat of breathing volunteer in the supine position using proposed method, simultaneously. In the result, body-surface velocity could be measured properly by proposed method using ultrasound. In addition, velocities by breathing and heartbeat could be measured simultaneously by using M-sequence signal and phase tracking technique.

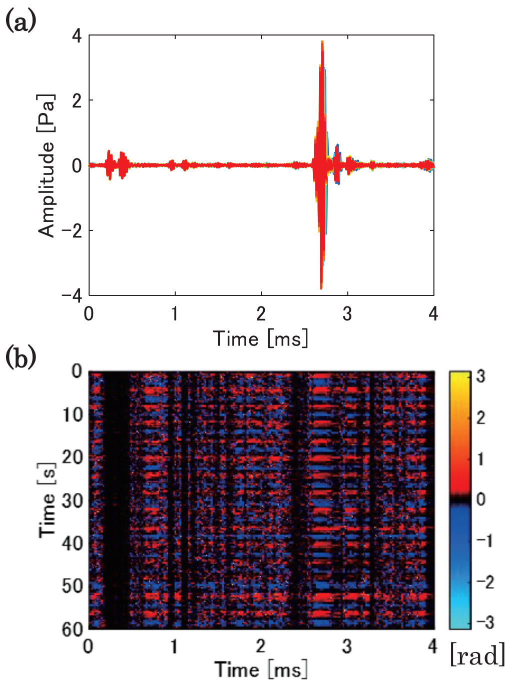

Fig. 2 (a) Received signal, (b) 2-D plot of phase difference.

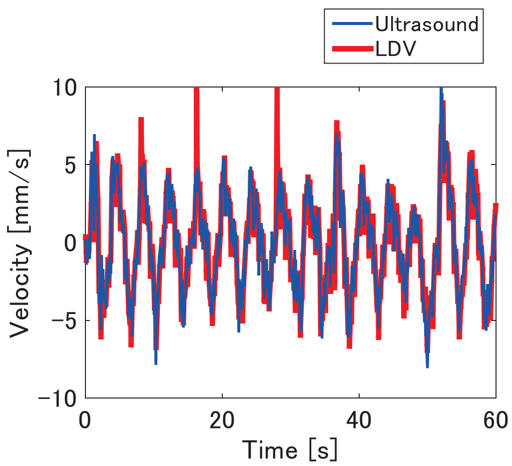

Fig. 3 Measured body-surface velocities.

References

1) R. Fukushima *et al*: Proc. of autumn meeting of ASJ (2010), 1431-1432.

2) K. Hoshba *et al*: Jpn. J. Appl. Phys. **52** (2013) 07HC15.

3) K. Hoshia *et al*: Proc. of autumn meeting of ASJ (2013), 1335-1336.

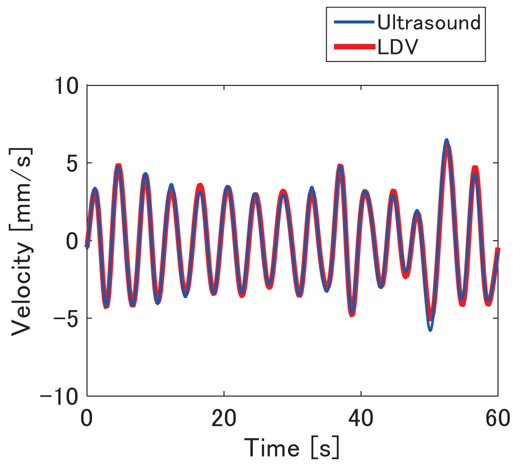

Fig. 4 Measured body-surface velocities using Filter 1.

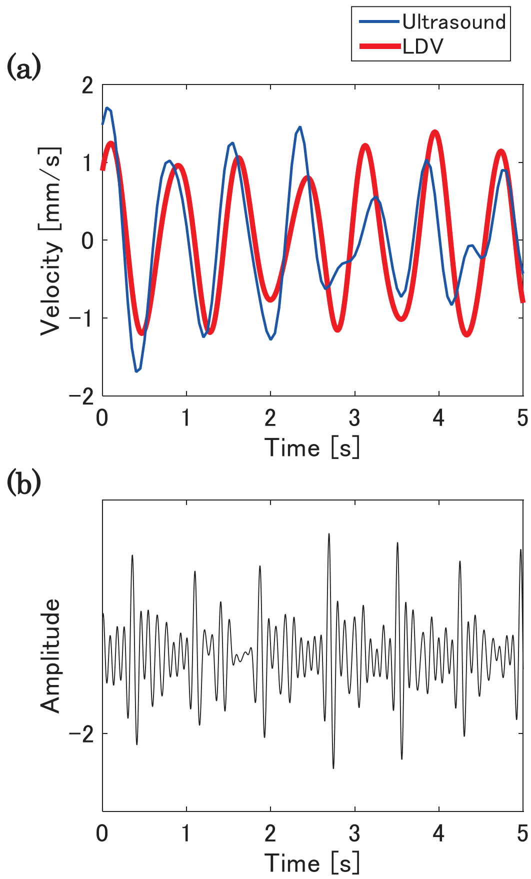

Fig. 5 (a) Measured body-surface velocities using Filter 2, (b) measurement result of the cardiac sensor.