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Non-contact measurement of displacement vector on chest surface by breathing and heartbeat using airborne acoustic image
空中音響画像を利用した呼吸・心拍による胸部変位ベクトルの非接触計測

Taiki Hayashi‡, Shinnosuke Hirata, and Hiroyuki Hachiya (Tokyo Tech)
林 泰輝‡, 平田 慎之介, 蜂屋 弘之 (東工大)

1. Introduction

Non-contact measurement of vital sign is advanced using various approaches. Measurement using ultrasound is inexpensive, non-invasive and easily signal processing compared with measurement using optical images and millimeter waves, and expected to apply in various situations. In previous studies, the chest displacement due to breathing and heartbeat is measured from ultrasonic transit time by using a pair of loudspeaker and microphone [1, 2]. In this report, measurement of displacement vector on the chest surface by airborne acoustic images created by using two microphones is described.

2. Measurement method of chest displacement

In this method, the chest displacement is measured by the pulse echo method with M-sequence pulse compression. An M-sequence modulated ultrasound is transmitted from the center loudspeaker. Reflected waves from the body surface are received by two microphones placed on the left and right of the loudspeaker. Received signals of two microphones are correlated with the transmitted M-sequence. The airborne acoustic image is formed from two obtained cross-correlation functions by the synthesis aperture focusing method. The brightness pixel in the image is determined as the reflection point on body surface in the frame. The displacement vector of the reflection point is calculated from the inter-frame phase difference.

3. Experiment

3.1. Measurement configuration

To measure the chest displacement due to breathing and heartbeat, the experiment by a subject in a spine position without clothes is conducted. The measurement configuration is shown in **Fig. 1**. The ultrasound is transmitted above the subject on the bed. The loudspeaker and two microphones are installed 690 mm above the bed. The experiment was performed in two situations when a subject was breathing and holding breath. Then, the subject breath at 4 second

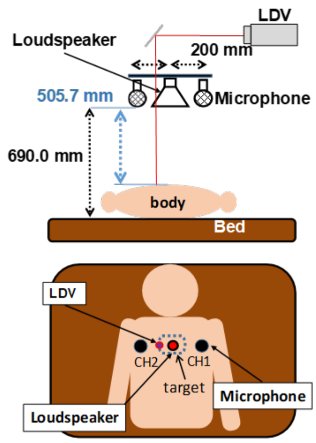

Fig. 1 Measurement configuration in a supine position without clothes.

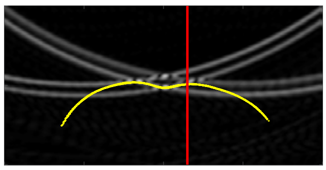

Fig. 2 The airborne acoustic image by synthetic aperture of cross-correlated functions.

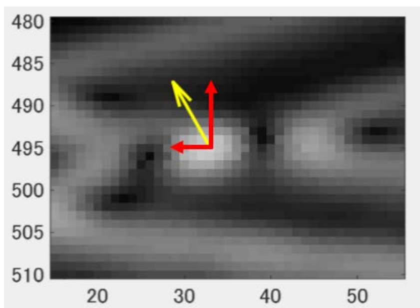

Fig. 3 The displacement vector of the reflection point is calculated from the inter-frame phase difference.

cycle according to the movie. In addition, a contact type pulse wave sensor (BIOPAC TSD 200) and a laser Doppler vibrometer (Polytec OFV 302) were used as a reference for the heartbeat cycle and displacement of the body surface.

hayashi@us.sc.e.titech.ac.jp, hachiya@sc.e.titech.ac.jp

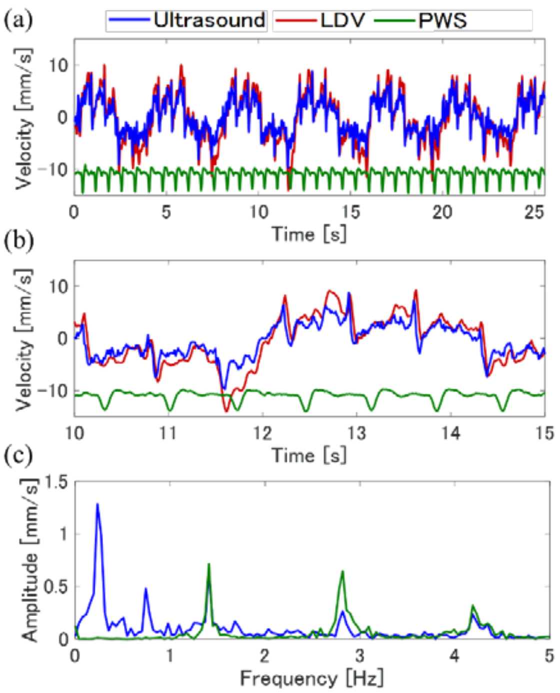

Fig. 4 Measurement results when the subject was breathing in a supine position without clothes, (a) measured velocity using Ultrasounds and LDV and PWS, (b) the enlarged view of (a), (c) the frequency spectrum of (a).

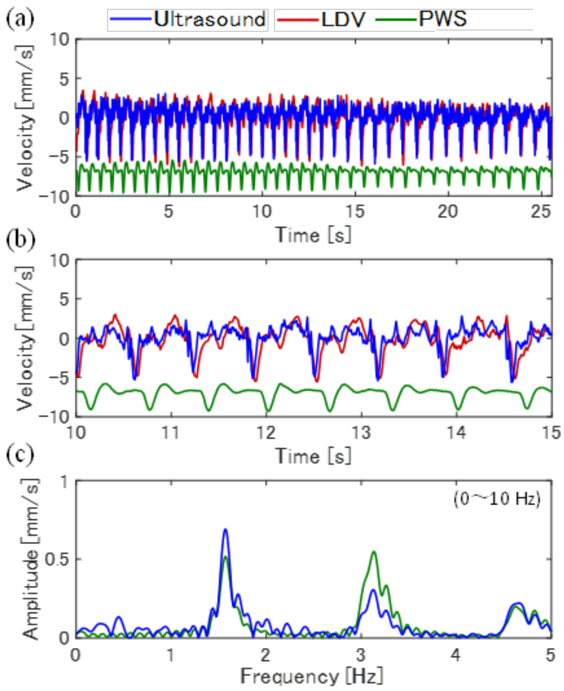

Fig. 5 Measurement results when the subject was holding breath in a supine position without clothes, (a)measured velocity using Ultra-sounds and LDV and PWS, (b) the enlarged view of (a), (c) the frequency spectrum of (a).

3.2. Experimental result

Fig. 2 shows the airborne acoustic image formed from cross-correlation functions. The brightness pixel around x = 40 mm and y = 500 mm seems the reflection point of the body surface. In this figure, the yellow line indicates body surface measured by 3D scanner. Therefore, the point of the body surface is the left and right two of the four looks like diamonds and the two points above and below are its artifacts. The red line in **Fig. 2** shows the measurement position in the LDV. **Fig. 3** shows two-dimensional displacement of body surface in this flame. The yellow line is the vector which is enlarged from the real size by 100 times. In this report, two-dimensional displacement on the measurement position in the LDV is calculated and the component which is vertical to the bed indicated by red line in **Fig. 3** is focused on. **Fig. 4** shows result of experiment when subject was breathing, and **Fig. 5** shows that one when subject was holding breath. In each figures, (a) shows superimposition of computed speed by ultrasonic wave, LDV and measurement result by pulse wave sensor (PWS). In addition, (b) is enlarged view of (a) and (c) is the frequency spectrum of (a). **Fig. 4** (c) shows the frequency spectrum of (a) in 0 s ~ 10 s because heart cycle was changed at near 13 s. As can be seen from (a) and (b) of **Fig. 4** and **Fig. 5**, measurement results by ultrasonic waves and by LDV are almost corresponding. As can be seen from (c) of **Fig. 4** and **Fig. 5**, there are the breathing frequency of 0.25 Hz and its harmonic components, and peaks are observed in 1.5 Hz at the time of breathing and holding breath, and these are corresponding with measurement result of PWS. Therefore these are frequency of heartbeat. As described above, in the supine position and without clothes, it is possible to observe the breathing and heartbeat from the two-dimensional displacement on chest obtained from the airborne acoustic image.

4. Conclusion

In this paper, non-contact measurement of displacement vector on chest surface by breathing and heartbeat using ultrasonic waves was studied. In the proposed method, the SNR of echo reflected from the body surface is improved by pulse compression using an M-sequence. Then, two-dimensional displacement is measured using phase tracking on the reflection point of the body surface in the airborne acoustic image created by using two microphones. It is possible that measurement displacement due to breathing and heartbeat when subject is in supine position without clothes.

References

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2. K. Hoshiba, S. Hirata, H. Hachiya, 2015 ICU, Physics Procedia, Vol.70, pp. 364-367, 2015.