3P5-12
Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 531-532
3-5 December, 2014

Speckle Imaging of Intracardiac Blood Flow with Suppression of Motion Artifact

モーションアーチファクトを低減した心臓内血流のスペックルイメージング

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1. Introduction

The relationship between the blood flow inside the human heart and the cardiac function has received attention in recent years. Echo particle image velocimetry (E-PIV) can visualize the direction of blood flow with movements of enhanced echoes and velocity vectors [1]. The drawback of E-PIV is, however, that the intravenous injection of contrast agent is required.

Previously, for visualization of the direction of cardiac blood flow, we proposed the high-frame-rate imaging of movements of blood echo speckle (BES), which is the speckle-like texture arises from interferences among echoes from tiny blood particles [2]. However, BES images suffered from the serious motion artifact in the *in vivo* measurement caused by a low directivity of a defocused transmit beam. In the present study, a method for reduction of the motion artifact in BES image was proposed and the effect of the proposed method was examined.

2. Principles

The acquisition of echo signals at a high-frame-rate was implemented by parallel receive beamforming with diverging beam transmission [3]. The echo data was acquired at the ultrahigh-frame-rate of 6250 Hz with the single transmission of a non-steered diverging beam per frame. The transmitted wave was diverged from the virtual point source placed at 30 mm behind the array and a 3.75 MHz phased-array transducer operated. Individual echo signals received by 96 transducer elements were sampled at 15 MHz and 241 focused receiving beams were created for each transmission. The B-mode was obtained by the novel phase coherence imaging with sub-aperture focusing, which was previously developed in our group [4]. This technique for beamforming is characterized by preserving speckle-like echoes with reducing the side-lobe level.

To enhance echoes from blood particles for BES imaging, echo signals were high-pass filtered in the direction of frame (called clutter filter), where the cut-off frequency was set to 500 Hz corresponding to the velocity of 10 cm/s at the ultrasound frequency of 3.75 MHz. The lower cut-off velocity is desirable to visualize echoes from blood particles with a wider range of velocity. However, the artifact from the fast-moving reflector except for blood particles (e.g., the cardiac wall and valve) can be seen in the BES image when the velocity of the moving object get over the cut-off velocity of the clutter filter. This artifact is prominent because the amplitude of the artifact echo from tissue is very high. Hence, it is necessary to reduce the artifact echo from the moving object without making the cut-off velocity high.

The coherence of echoes, which corresponds to the inter-frame change of phase of echoes, from the cardiac wall and valve (artifact in BES image) show higher value than that of echoes from blood particles [5]. In this study, a method for rejection of artifact echoes using the machine learning technique with the coherence was proposed. First, the frame, in which the object moves faster than the cut-off velocity corresponding to the frequency of f_{c1} (= 500 Hz) set for BES imaging, is identified. Let us assume that the artifact echo significantly arises in this frame. The velocity is estimated using the auto correlation technique applied to echo signals which were low-pass filtered in the direction of frame to enhance echoes from objects except for blood particles. Next, the coherence in this frame is computed from echo signals, which are high-pass filtered to suppress echoes from stationary objects (e.g., ribs) at the lower cut-off frequency f_{c2} (= 100 Hz) than f_{c1}. Finally, artifact echoes are automatically identified by the *k*-means clustering algorithm [6] using the coherence and BESs are not visualized at identified points. This proposed algorithm is performed in only the automatically identified frame for better computational efficiency. However, the coherence in the cardiac lumen is seriously increased due to the large side-lobe echo from surrounding myocardia caused by low directivity of diverging transmit beam in this study. Therefore, the differentiation of the artifact from the

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cardiac lumen is difficult. To decrease the coherence in the cardiac lumen, white noise was added to the filtered echo signals as follow:

$$s'(i) = s_{\mathrm{hpf}}(i) + g_{\mathrm{n}} \cdot n(i),$$

where i, $s_{\mathrm{hpf}}(i)$, g_{n}, and $n(i)$ denote the frame number, the amplitude of filtered echo signal, the gain of noise signal, and white noise with standard deviation of 1.0.

3. Result and Discussion

The *in vivo* measurement of a 27-year-old healthy male was performed. Figure 1(a) shows the BES image (hot-scale) overlaid on the B-mode image (gray-scale) in the frame automatically identified by the proposed algorithm in the early diastole. The artifact caused by echoes from the cardiac valve was emphasized. Figure 1(b) shows the coherence image in this frame. The values of coherence in the cardiac wall and lumen were comparative; therefore, it is difficult to differentiate these regions. The image of coherence of echo signals containing the noise signal (g_{n} = 80) is shown in Fig. 1(c). The coherence in the cardiac lumen was reduced while that in the heart wall and the cardiac valve was relatively preserved. A large part of artifact was masked with the proposed method, as shown in Fig. 1(d), using the coherence shown in Fig. 1(c).

4. Conclusion

In this study, a method with the coherence of echoes for reduction of the moving artifact in BES image was proposed. It was confirmed that the injection of noises to echo signals was effective to identify artifact echoes based on the coherence. In *in vivo* experiment, A large part of artifact echoes was reduced by the proposed method.

Acknowledgment
This work has been supported by JSPS Research Fellowships for Young Scientists (DC1) and International Advanced Research and Education Organization of Tohoku University.

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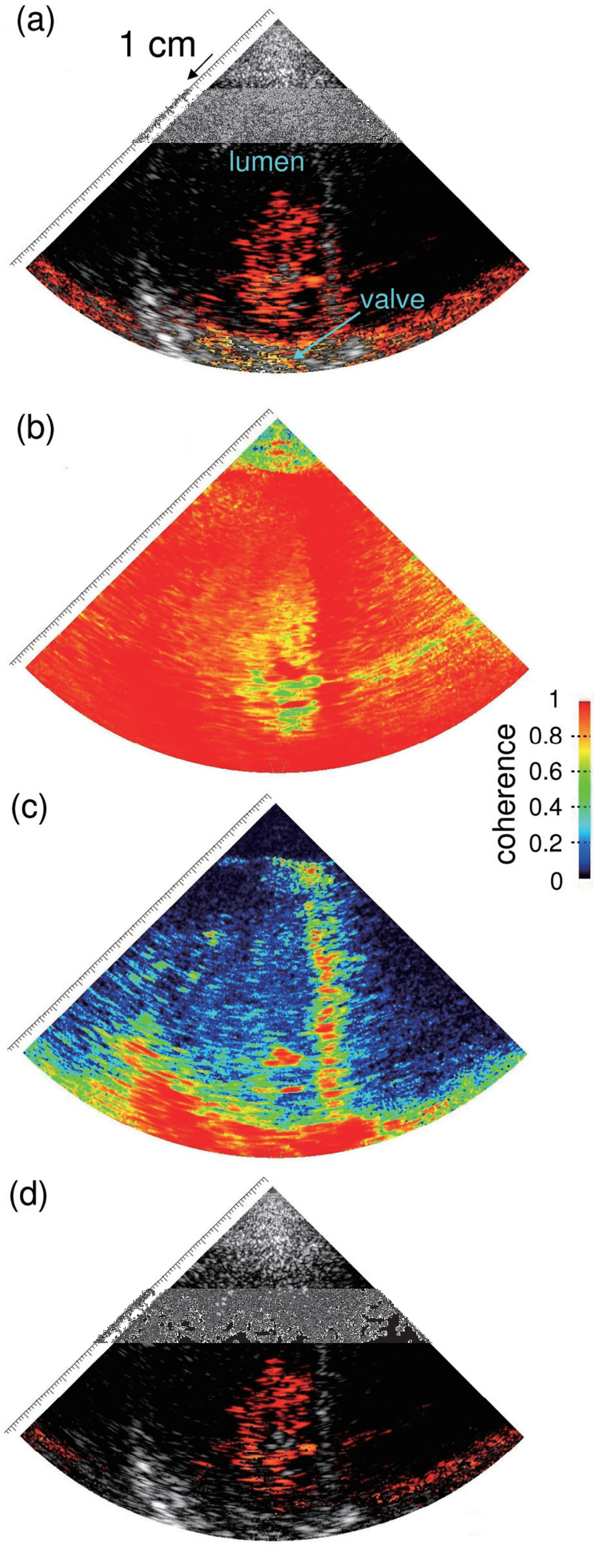

Fig. 1 (a) BES image, (b) conventional coherence image, (c) coherence image obtained by adding noises to echo signals, and (d) BES image with reduction of artifact echoes by the proposed method in the automatically identified frame.