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2-D Blood Flow Vector Imaging in Common Carotid Artery Based on 2-Step Block Matching Method Using Envelope and RF Signals

包絡線・RF 信号を用いた 2 段階ブロックマッチング法による 2 次元血流ベクトル推定

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1. Introduction

Developments on high temporal resolution ultrasonic measurements using plane or diverging waves[1,2] enable to visualize the dynamics on blood flows[3,4]. However, there is no gold standard for the estimation techniques of the 2-D velocity.

This paper focuses on the estimation precision of block matching method[3, 5, 6], which is one of the most common techniques for 2-D motion tracking. Some research groups developed multi-level speckle tracking method, which consists of rough and fine detections in at least 2 steps. Fekkes *et al.*[7] proposed that the combination of the rough detection with envelopes and the fine detection with RF signals were proper for the block matching for estimation of the wall displacement. However, it is not revealed that whether this combination is also proper for the faster velocities.

An objective is to reveal the moost proper combination of signals used for the block matching method for estimation of flow velocities (up to 1 m/s). In this paper, the estimation precisions are compared using the 2-step block matching method with three different strategies for calculation of correlation coefficients using RF, envelopes, and the combination of the RF with the envelopes. Also, the 2-step block mathcing method with the best strategy is applyied to data in common carotid artery.

2. Materials and methods

2.1 Experimental setup

Ultrasonic echo signals were measured with a 7.5MHz linear array ultrasonic probe, which has 192 transducer elements with an element pitch of 0.2 mm. The echo signals were received with individual transducer elements using a programable acquisition system with 96 transmit-receive channels. The sampling frequency was 31.25 MHz. To achieve a high-temporal resolution, plane-wave based imaging was employed[1,2]. In one plane-wave transmission, 24 focused beams were created at intervals of 0.2 mm by receive beamforming. One image frame consisting of 96 beams was obtained by 4 emissions of plane waves.

A phantom experiment was performed to evaluate the estimation precision. The probe was fixed on a three-axle automatic stage, and moved two-dimensionally at a constant speed. The lateral and axial velocities (v_x, v_z) were 2 and 1 mm/s, respectively. Also, velocities of 4-800 mm/s were simulated by decimating the frames by a factor of n: $(v_x,\ v_z) = (2n,\ 1n)$ [mm/s]. In this phantom experiment, the pulse repetition frequency was set at 5208 Hz, resulting in a frame rate of 1302 Hz.

RF echo signals from a common carotid artery (CCA) of a 44-year-old healthy male were acquired in a frame rate of 2604 Hz.

2.2 2-step block matching method

A flow chart was shown in **Fig.** 1. The detailed procedure was described in the previous paper[7]. First, template and search region were chosen in the reference and successive frames, respectively. In this paper, sizes of a search region along the lateral and axial directions were set to 10 and 40 pixels, respectively. The correlation function was calculated from these frames to search a pixel-level displacement. Also, to achieve a finer (subpixel-level) displacement estimation, the interpolation was applied to the correlation function around the position where the correlation coefficient was maximum. In the proposed method, the envelope and the RF signals were used for the rough and finer searches of the peak of the correlation function, respectively. Finally, the velocities were obtained by multiplying the displacment by the frame rate.

3. Results and discussions

Figs. 2 (a) and (b) show bias errors of the estimated velocities along the lateral and axial

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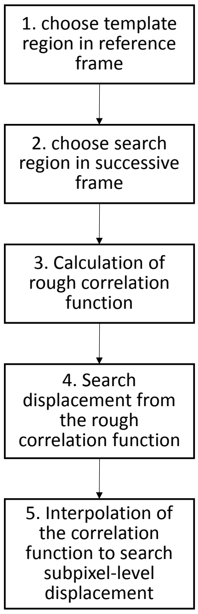

Fig. 1 Flow chart of 2-step block matching method

directions, respectively. In the slower velocity range of less than 40 mm/s, the bias error of the proposed method was almost equal to that of the block matching using RF signals. Meanwhile, in the faster velocity range of more than 400 mm/s, the bias errors by three methods were same. However, the bias error obtained with RF signals was deteriorated between the velocities of 50 and 200 mm/s. The velocity corresponded to the displacement of 38.4 and 154 μm, which meant that the template moved to the fringe of a point spread function (PSF) of the system. Hence, this result indicated that the shape of the PSF influenced the estimation precisions of the block matching method.

Fig. 3 shows a 2-D velocity map of a CCA

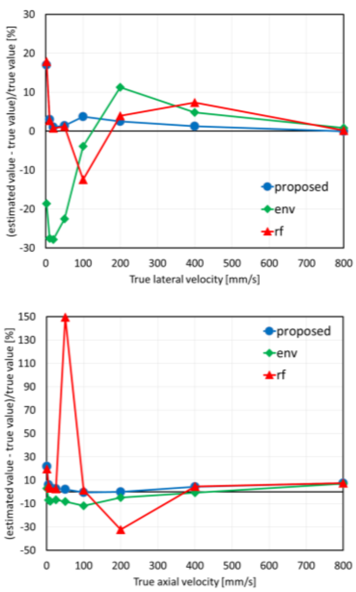

Fig. 2 Bias error of the estimated velocities along (a: upper) lateral, and (b: lower) axial directions.

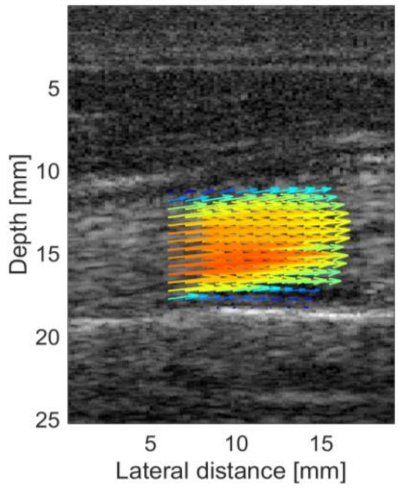

Fig. 3 2-D velocity map of the CCA region

region obtained by the proposed method. The velocity vector could be clearly observed.

4. Conclusions

In this paper, the estimation precisions were compared by applying three different block matching strategies to reveal that the proposed method with the combination of envelope and RF signals was proper for the investigated velocity range. Also, the phantom study indicated the shape of the PSF affected the precisions. We will investigate the relationship between the shape of the PSF and estimation precision.

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