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Basic Study of Medical Ultrasound Blood Velocity Estimation Using Correlation Considering Randomly Changing Distribution of Red Blood Cells

赤血球分布のランダム変化を考慮した相関による医用超音波血流速度推定法の基礎検討

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1. Introduction

Doppler ultrasound technique is one of the most common techniques to measure blood flow velocity. This method derives the mean axial velocity at each location from the measurement of the gradual translation of echoes between successive pulse returns [1]. However, the measurement accuracy of the technique in blood flow velocity deteriorates when an acoustic beam is perpendicular to a vessel.

Another technique uses the cross-correlation between two echoes of different scan lines to measure blood flow velocity. Conventional blood velocity estimators use the cross-correlation without the consideration of randomly changing distribution of red blood cells (RBCs). In this study we consider the influence of random change on the correlation coefficient between two echoes of different scan lines to improve the accuracy of the blood flow velocity measurement.

2. Blood Velocity Measurement Using Cross-correlation between Echoes of Different Scan Lines

A cross-correlation technique measures the time-shift corresponding to the best match between successive B-mode images. The conventional blood velocity measurement using a cross-correlation technique estimates the blood velocity using the distance between the regions of the best match and the measured time-shift, as shown in **Fig. 1**. When scan lines Q and Q' are the best match, the blood velocity estimated by the conventional method is

$$v = n\Delta\xi / (m+n)\Delta\tau, \qquad (1)$$

where $\Delta\xi$ is the scan line interval, $\Delta\tau$ is the acquisition-time interval between adjacent scan lines, $n\Delta\xi$ is the distance between scan lines Q and Q', and $m\Delta\tau$ is the acquisition time of a single B-mode image. However, the conventional method ignores randomly changing distribution of RBCs.

Since the distribution of the red blood cells changes randomly, the cross-correlation coefficient between two regions of best match decreases in inverse response to the measurement time

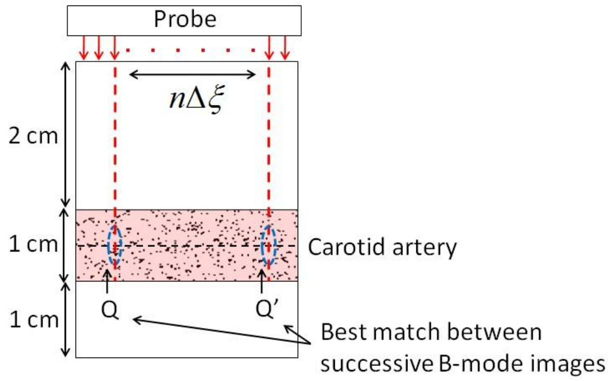

Fig. 1 Schema of the estimation of blood flow velocity using a cross-correlation technique. The estimator measures the time-shift corresponding to the best match between successive B-mode images. $n\Delta\xi$ is the distance between the couple of regions, where they are the best match.

difference between two regions. When no blood flow exists, both the increase of the acquisition-time difference and the increase of the distance between two measurement points reduce the cross-correlation between the two measurement points. In this case the contour of equal correlation coefficients between couples of measurement points depicts a circle on the correlation map, as shown in **Fig. 2** [2]. When a blood flow exists, the contour of equal correlation coefficients between couples of measurement points depicts an ellipse on the correlation map. Since the measurement time of each scan line in the same frame varies in response to the lateral position of the scan line, the conventional correlation technique searches the position of the maximum correlation coefficients along the line with the slope angle of $\Delta\tau/\Delta\xi$ on the correlation map, i.e. this technique selects the point P in Fig. 2 to estimate the blood velocity. Therefore, the blood velocity calculated by the conventional correlation technique has an estimation error.

The measurement of the blood velocity requires the estimation of the shape of the ellipse. In this study we propose a blood velocity measurement method using the estimation of the contour shape of correlation coefficients. The proposed method utilizes multiple measurement points to calculate the correlation coefficients of

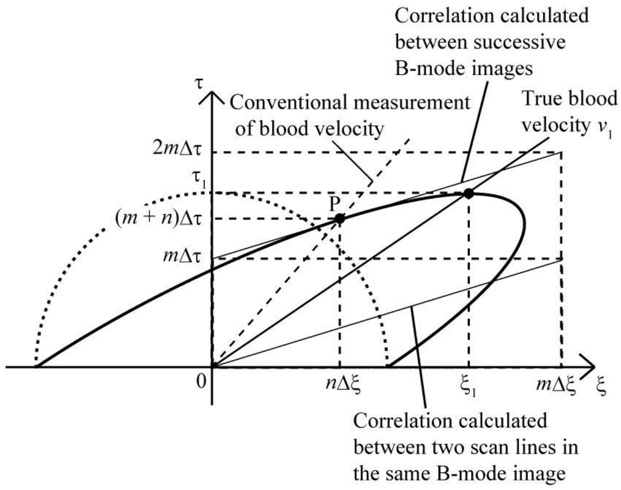

Fig.2 Contour of equal correlation coefficients between couples of measurement points in an artery considering randomly changing distribution of red blood cells. ξ and τ denotes the distance and time difference between two measurement points, respectively. The true blood flow velocity v_1 is equal to ξ_1/τ_1. P indicates the position of the maximum cross-correlation between the successive B-mode images.

various points on the correlation map. When the number of the utilized measurement points is M, we calculate the correlation coefficients of no more than ${}_MC_2$ points on the correlation map. The proposed method selects the blood velocity with the correlation profile, where its correlation coefficients and the measured correlation coefficients at the calculated points are the best match.

3. Blood Velocity Estimation Using the Proposed Method

We investigate the performance of the proposed blood velocity estimation method using a 2-D digital tissue map that simulates a human carotid artery. A tube runs parallel to the ultrasound probe at the depths from 2 to 3 cm, and the water flowing in the tube contains 45000 minute particles per cm^2 that mimick RBCs. **Fig. 3** shows a correlation map when the mean and standard deviation of the blood flow velocity are 1.5 and 0.10 m/s, respectively. The proposed method estimates the blood velocity from the correlation coefficients at several positions on a correlation map.

We assume that the blood velocity is supposed to be constant for 50 ms. When $\Delta\tau$ = 50 μs we can utilize a total of 1000 measurement points to estimate the blood velocity. In this study we set the number of measurement points M as 10. This means that the number of incoherent integration is 100, where incoherent integration is applied at the calculation of the cross-correlation between each target couple to suppress the variation

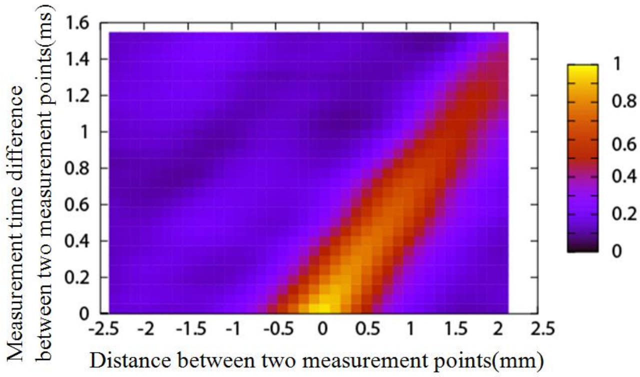

Fig.3 Correlation coefficients between couples of measurement points when the mean blood velocity is parallel to the artery wall and its norm is 1.5 m/s. The velocity dispersion is omni-directional, and the standard deviation of the velocity is 0.1 m/s.

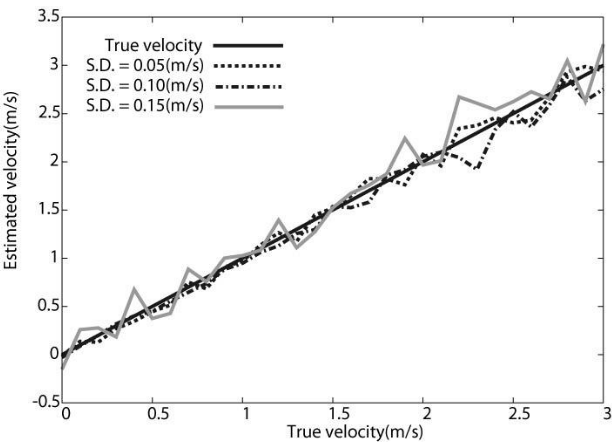

Fig.4 Blood flow velocity estimated by the proposed method. S.D. denotes the standard deviation of the blood velocity.

of each correlation coefficient.

Fig. 4 shows the blood flow velocity estimated by the proposed method. The proposed method succeeds to estimate the blood velocities from 0 to 2 m/s within the estimation error of 0.1 m/s when the velocities of the minute particles have the standard deviations of 0.05 and 0.10 m/s. The proposed method works within the estimation error of 0.5 m/s in the severe condition that the velocities of the minute particles have the standard deviation of 0.15 m/s. These results imply the potential of the proposed method to improve the measurement accuracy in blood flow velocity.

References

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2. B. H. Briggs, MAP Handbook, 13, (1984) 166.