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Improvement of Displacement Estimation of Heart Wall by Using Its Deformation in Calculation of Cross-Correlation between Ultrasonic RF Signals.

心筋の変形を考慮した RF 信号間の相関算出による心臓壁の変位推定の高精度化

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1. Introduction

2D speckle tracking method[1)] is used for diagnosis of heart function. However, in conventional tracking algorithm, myocardial deformation caused by contraction and relaxation often becomes problematic[2)]. In calculation of cross-correlation between ultrasonic RF signals for estimation of displacement of heart wall, motion accompanied by deformation of cardiac muscle (not only parallel motion) decreases correlation between RF signals and leads to estimation error.

In addition, when the part producing strong echo, such as pericardium or valve, is contained in a correlation kernel, erroneous estimation is likely to occur because contributions of echoes from other parts is significantly reduced.

In the present study, to decrease tracking error due to deformation of the heart wall and heart tissue producing strong echoes, we developed a displacement estimation method with better accuracy by considering the above-mentioned problems.

2. Principle

To reduce the influence of deformation, in the present study, displacement was estimated using two-step tracking method. In the first step, we estimate the displacement of a target point coarsely using a correlation kernel consisting of a number of small blocks. In the second step, we estimate conclusive fine displacement using a smaller kernel consisting of the blocks.

2. 1. Coarse estimation by separated kernel

In the first step, larger kernel ($10\times10\,\mathrm{mm}^2$) separated into 5 blocks both in lateral and axial directions (total number of blocks are 25) is used. Local correlation $\gamma_{xy}(\boldsymbol{p})$ between RF signals is calculated for each separated kernel. Then, by multiplying $\gamma_{xy}(\boldsymbol{p})$ by weighting function w_{xy}, the central part of a kernel is subjected to a higher weight than outside parts. Then, the weighted sum of correlation functions $\gamma_{xy}(\boldsymbol{p})$ for separated kernels, total correlation $\gamma(\boldsymbol{p})$ was defined by:

$$\gamma(\boldsymbol{p})=\frac{\sum_{x=-2}^{2}\sum_{y=-2}^{2}w_{xy}\gamma_{xy}(\boldsymbol{p})}{\sum_{x=-2}^{2}\sum_{y=-2}^{2}w_{xy}}. \qquad (1)$$

As illustrated in Fig. 1(a), position $\boldsymbol{p_1}$ is the point giving the highest correlation in the search region. In the proposed method, coarse displacement $(\boldsymbol{p_1}-\boldsymbol{p_0})$ is decided in the first step. This approach reduces the effect of the difference in echo amplitude by calculating correlation function in each local block. Thus, the erroneous estimation can be suppressed even when a part producing an extremely strong echo is included within the correlation kernel.

2.2. Fine estimation by smaller kernel

In the second step, a smaller kernel ($6\times6\,\mathrm{mm}^2$) is used to estimate the fine displacement of the target point. Smaller kernel is relatively unaffected by deformation of the heart wall. However, when the kernel size is too small, erroneous estimations often occur because there can be similar RF signal patterns in a search region[3)]. Therefore, a small search region is assigned around the position $\boldsymbol{p_1}$, and fine displacement $(\boldsymbol{p_2}-\boldsymbol{p_0})$ is estimated.

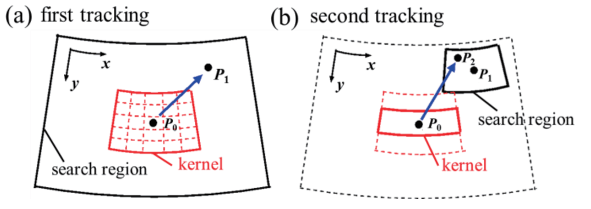

Fig. 1 Displacement estimations using (a) separated kernel and (b) small kernel.

3. Experiment

The proposed two-step tracking method was validated by the following experiments. As shown in Fig. 2(a), a silicone phantom $(60\times80\times80\,\mathrm{mm}^3)$ is attached to fixed base and the displacement and

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deformation of the phantom were generated by an actuator. Then, we obtained RF signals using parallel beam forming (PBF)[4] and conventional and proposed speckle tracking methods were applied. Acquired B-mode image is shown in Fig. 2(b). In this experiment, the frame rate was 860 Hz. Velocity of the plate attached to the actuator measured by a laser displacement meter was about 5 mm/s. However, velocity of the heart wall typically reaches to 50 mm/s in the diastolic phase[5]. Therefore, by setting the interval in calculation of correlation function to be 10 frames, displacement between frames became similar to actual velocity of the heart wall. The position of interest was located at 40 mm from the ultrasonic probe.

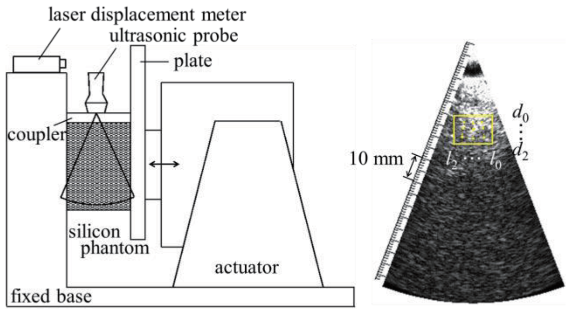

Fig. 2 (a) System of experiment. (b) Target points on B-mode image of silicone phantom.

The true displacement and velocity at each point are calculated from displacement of the plate pushing the silicone phantom measured by the laser displacement meter. By assuming that the displacement is linearly decreased with the distance from the plate attached to the actuator and becomes zero at the fixed base, the theoretical displacement of the point of interest can be obtained.

As an indicator for assessment of accuracy, the root mean square error (RMSE) is adopted. Ultrasonic and laser measurements were applied separately because it was difficult to use the laser displacement meter and ultrasonic probe at the same time. The RMSE $\varepsilon_{l_i d_j}(\tau)$ was estimated using the estimated displacement wave $x_{l_i d_j}(n)$ and true displacement wave $x_{l_i d_j 0}(n)$ during one cycle of motion of the actuator as follows:

$$\varepsilon_{l_i d_j}(\tau)=\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left\{x_{l_i d_j}(n-\tau)-x_{l_i d_j 0}(n)\right\}^2} \qquad (2)$$

where τ_{min} is the time delay which gives the minimum RMSE. Then, the minimum RMSE $\varepsilon_{l_i d_j}(\tau_{min})$ is employed to evaluate accuracy of displacement estimation because the time delay between the estimated displacement $x_{l_i d_j}(n)$ and true displacement $x_{l_i d_j 0}(n)$ was unclear. The RMSE of velocity is also calculated in the same way.

As a result of taking the average of the minimum RMSE $\varepsilon_{l_i d_j}(\tau_{min})$ of all analyzed points, the evaluated RMSE are summarized in Table 1. Average RMSE obtained by the conventional method was considerably reduced than that obtained by the proposed method.

Table 1 Average RMSE by each method

	Proposed method	Conventional method
Displacement [mm]	0.129	0.156
Velocity [mm/s]	1.063	1.216

Displacements estimated by the proposed method, conventional method, and true displacement measured by the laser displacement meter are shown in Fig. 3. The proposed method realized a higher accuracy as shown in Fig. 3.

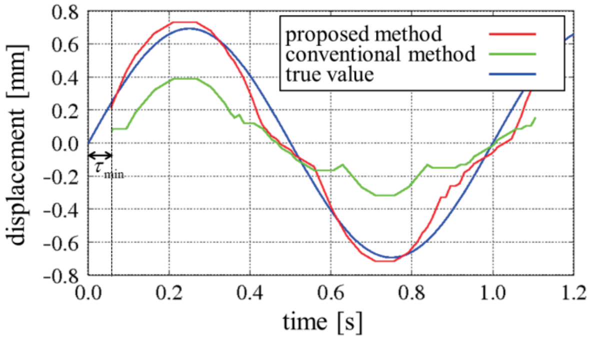

Fig. 3 Displacements estimated by respective methods and true displacement.

4. Conclusion

In this study, we proposed a two-step tracking method which estimates coarse displacement at first using a separated kernel and, then, determines fine displacement using a smaller kernel. We conducted an experiment using a silicone phantom, which was compressed by an actuator, to evaluate the accuracy of our proposed method.

The RMSE obtained by the proposed method was smaller than that obtained by the conventional method. Therefore, it is confirmed that accuracy of the proposed two-step tracking algorithm is superior to the conventional method, and a potential of the proposed method for accurate estimation of the cardiac motion was shown.

References

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