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Optimization of Feature Extraction from Ultrasonic RF Echoes for Identification of Heart Wall Regions

心臓壁領域同定のための超音波 RF 信号の特徴抽出の最適化

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1. Introduction

Currently, both cardiac wall motion and strain rate can be quantitatively evaluated by means of ultrasound Doppler method or speckle tracking technique. In most of these methods, the heart wall, which is the object to be analyzed, is manually identified by an operator. However, this task is tedious and it suffers from inter- and intra-observer variability. For facilitation of analysis and elimination of operator dependence, automated identification of the heart wall region needs to be realized. We have been studying on identification of heart wall regions in long-axis view (**Fig. 1**(a)) of the left ventricle. However the proposed methods have not yet applied to identification of the heart wall regions in other views, such as short-axis view (Fig. 1(b)). Applying the method for data of short-axis view of left ventricle is difficult. The main reason is that the lateral wall motion in short-axis view, which is mainly in the direction perpendicular to the ultrasonic beam, triggers a decrease of the effect of the method. In the present study, we investigated optimal conditions for feature extraction from ultrasonic RF echoes to realize identification of the heart wall regions in the short-axis view.

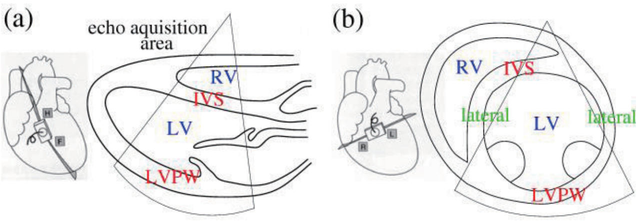

Fig. 1. Illustrations of measurement by transthoracic echocardiography in (a) long-axis view and (b) short-axis view of left ventricle (RV: right ventricle, LV: left ventricle, IVS: interventricular septum, LVPW: left ventricular posterior wall).

2. Principle

In this study, the proposed method[1)] for identification of heart wall regions is based on pattern recognition using multiple features extracted from ultrasound RF signals. After identification in the frame of interest (FOI) by pattern recognition, heart wall regions in the successive frames are identified by tracking each point classified as the heart wall regions in the FOI using the *phased-tracking method* [2)]. Employed first feature is the logarithmic amplitude of envelope-detected RF signal, which corresponds to the gray level of an ultrasonic image. The second feature is the magnitude–squared coherence (MSC) function[3)], which deals with the phase of RF signal. With respect to MSC, to track accurately the motion of the heart wall by the *phased-tracking method*, ultrasonic echo signal was aquired at a high frame rate the motion of the heart wall can be tracked accurately by the *phased-tracking method*. On the other hand, blood cells in the cardiac lumen are difficult to be tracked because they slip away from the focal area of an ultrasonic beam owing to blood flow in different directions from that of the ultrasonic beam. The temporal changes in phases of echo signals in the kernel, where MSC is extracted, caused by the global motion of the heart wall can be compensated because the echo signal is only time-shifted by contrast to blood cells. Therefore, there is a significant difference in the temporal changes in the waveforms of ultrasonic echoes in the regions of wall and lumen. Using the complex spectra $\{Y(f;\, n)\}$ of the RF signal at frequency f in the n-th frame, the characteristics of phase changes of echoes in kernel between two consecutive frames are evaluated by the MSC function as follows:

$$|\gamma(f;n)|^2 = \frac{\left|\mathrm{E}_k\left[Y^*(f;n+k)Y(f;n+k+1)\right]\right|^2}{\mathrm{E}_k\left[|Y(f;n+k)|^2\right]\mathrm{E}_k\left[|Y(f;n+k+1)|^2\right]} \quad (1)$$

where $\mathrm{E}_k[\cdot]$ and denote the time averaging (for N frames).

3. Optimization of the feature extraction for short-axis view of left ventricle

As stated above, applying this method for data of short-axis view of left ventricle is difficult. The reason is that the MSC in the lateral wall region is low due to the loss of tracking accuracy because the motion of the lateral wall is mainly in the direction

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perpendicular to the ultrasonic beam. The features show a lower separability in shot-axis view than long-axis view due to decreases of the MSC of the heart wall region. For improvement of the low MSC in the heart wall region in short-axis view, the number N of frames for calculating MSC, was optimized. MSC in the lateral wall is possibly low when the number N is large because the tracking error is more likely to occur. Therefore, smaller N would be effective to improve MSC in the heart wall in short-axis view. Therefore, in this study, the number N was optimized in addition to selection of the cardiac phase for pattern recognition. We evaluated the separability of features for short-axis view at the intervals of 20 ms throughout a cardiac cycle. For evaluation of the separability we used the criterion of separability J [4)], which is calculated by the features extracted from the manually assigned regions of wall and lumen. **Fig. 2**(a) shows the criterion of separability J calculated with different numbers of frames N. Periods A, B, C, D and E denote the ejection phase, isovolumic relaxation phase, rapid filling phase, slow filling phase and atrial systole.

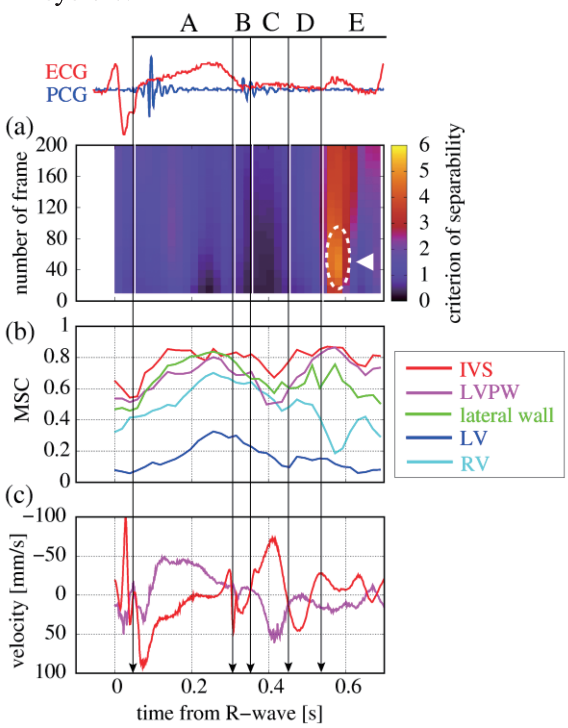

Fig. 2. (a) Criterion of separability J. Spatial means of (b) the MSC in each region manually assigned. (c) Velocities in IVS and LVPW.

As shown in Fig. 2(a), the maximal value of J is found in the atrial systole (E). For long-axis view, the slow filling phase (D) is the best phase for separability owing to the large difference in MSCs between the heart wall and lumen regions. However, in the slow filling phase, the heart wall motion is faster than that in the atrial systole as shown in Fig. 2(c). The decrease of MSC in the lateral wall (green line in Fig. 2(b)) degrades the separability for short-axis view due to the lateral motion of lateral wall in this period. Therefore, the atrial systole (E) is the best period because in this period the lateral wall motion is smaller than the slow filling phase. Moreover, the optimal number N resulted in 60, which is smaller than that of the long-axis view (N = 100). The reason is that the error in tracking heart wall in short-axis view is more likely to be occured than long-axis view due to lateral. Therefore, the optimal number N resulted in 60. **Fig. 3** shows the result of identification of the heart wall region in the optimal period (E) using the optimal number of frames $N = 60$. As shown in Fig. 3(c), the classes of the heart wall region (red and green plots) and the lumen region (aqua plots) are separated. From these results, we have shown achievement of the improvement of separability in short-axis view.

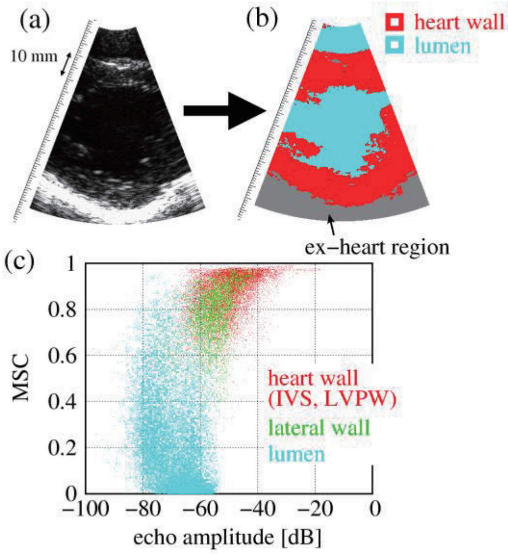

Fig. 3. (a) Original B-mode image. (b) Region-identified image (red: heart wall, aqua: lumen, gray: ex-heart]. (c) Distribution of features (red: IVS and LVPW, green: lateral wall, aqua: lumen).

4. Conclution

We achieved the improvement of separability for short-axis view by optimization of the selection of cardiac phase and the parameter for extraction of the features.

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