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Estimating Accuracy of Synchronization by Electrocardiogram for Reconstruction of 3D Ultrasonic Data

超音波 3 次元データ再構築のための心電同期の精度評価

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1. Introduction

Ultrasonic imaging for mesurement of myocardial strain or strain rate in the heart wall is efficient in quantitative assessment of regional myocardial function[1,2]. In recent years, methods for the noninvasive mesurement of regional myocardial contraction and relaxation have been desired.

In our group, the propagation of myocardial contraction and relaxation have been investigated from strain rate mesured by the *phased tracking method* which enables the detection of small vibrations in the heart wall[1,3]. Although the 2D distribution of strain rate was measured in [3], the contraction and relaxation propagate three dimentionally and some of the mechanisms of the 3D transition of myocardial contraction and relaxation still remain unclear.

Methods for noninvasive 3D mesurement of the heart wall have been developed, and it enabled to measure 3D distribution of strain[4]. In this method, the frame rate is several tens of Hz[4]. However, some transitions rapidly occur during a short period of about 10 ms[5]. Therefore, the continuous observation of such short transition requires a frame rate of higher than a few hundred Hz. In this study, ultrasonic beams were scanned sparsely so that the myocardial strain rate could be meaured in a wide area at a high temporal resolution of about 1/500 s[6].

Futhermore, we measured sevearal ultrasonic datasets in different 2D image planes sliced by mechanically moving an ultrasonic probe like a waving fan with angular intervals of a few degrees to obtain 3D data. At that time, we syncronized each slice data with the R-wave in electrocardiogram (ECG). If there is a large difference between times of the R-wave in ECG and slice data beat by beat by the error, it is difficult to observe the propagation of vibration in the heart wall. Therefore, in this study, an *in vivo* experiment was conducted to decrease such error, and the time of R-wave was detected accurately.

2. Principle

2.1 Synchronization by Electrocardiogram

As illustrated in **Fig. 1**, we obtain ultrasonic data in some slices during acuisiton periods which are synchronized with the R-wave in ECG. A slice datum at a constant same delay time from the R-wave is obtained and then, the probe moves to the next slice. This operation is repeated several times to obtain volume data during a specific cardiac phase.

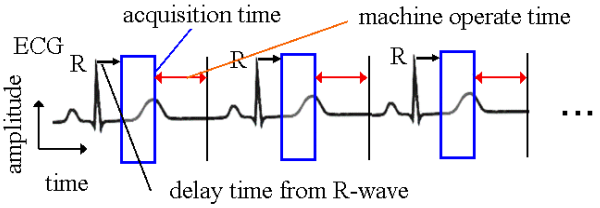

Fig. 1. Principle for synchronization of ECG to obtain volume data.

2.2 Synchronization Error

The ultrasonic RF data was acquired using a 3.75-MHz sector-type probe of ultrasonic diagnostic equipment (ALOKA SSD-6500). The sampling frequency of the RF signal was 15 MHz. The velocity of interventricular septum (IVS) was measured by the *phased tracking method*[1,3]. p points interpolated into each of the ECG and the velocity waveforms[7]. For interpolated signals, autocorrelation functions are obtained with respect to the partial ECG and velocity data of 200 ms in length around their peaks in the first cardiac cycle. From the autocorrelation functions, the times $\{t_e(p,n)\}$ and $\{t_v(p,n)\}$, which are the times of peaks in autocorrelation functions of ECG and velocity in the n-th heart beat, respectively, are obtained.

The time difference of the n-th peaks of ECG and velocity is given by

$$\tau(p,n) = t_v(p,n) - t_e(p,n) \qquad (1)$$

Time difference $\tau(p,n)$ was influenced by interpolated points p. Therefore, interpolated points p was examined so that variation of $\tau(p,n)$ was minimized.

From the minimized time difference $\tau(p,n)$, the times of n-th R-wave, $\{T_R(n)\}$, are given by

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$$T_R(n) = T_R(0) + t_e(p,n), \quad (2)$$

where $T_R(0)$ is the time of ECG peak in the first cardiac cycle. Finally, we detected the times of R-wave, $\{T_R(n)\}$ of accurately.

3. *In Vivo* Experiment

Figure 2 shows ECG and myocardial velocity of the heart wall obtained from a healthy 24-years-old male in several heartbeats. In **Fig. 2**, the red line is ECG, and the green line is the velocity of the heart wall. The blue and violet lines show periods of the partial data for calculation of the autocorrelation functions of ECG and velocity, respectively.

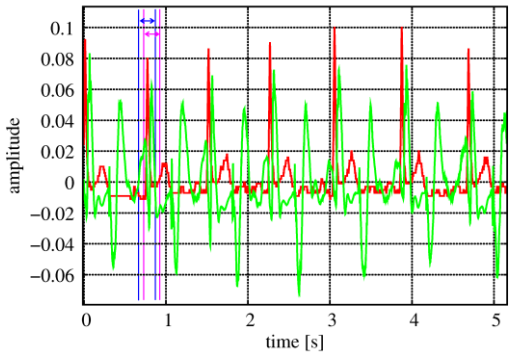

Fig. 2. ECG (red line) and the velocity of heart wall (green line). The blue and violet lines show periods of the partial data for calculation of autocorrelation function.

Figure 3 shows autocorrelation function of ECG and velocity. In **Fig. 3**, the red line means ECG, and the green line means velocity of the heart wall. We determined $t_e(p,n)$ and $t_v(p,n)$ from **Fig. 3**. Furthermore, time difference $\tau(p,n)$ was obtained from Eq. (1).

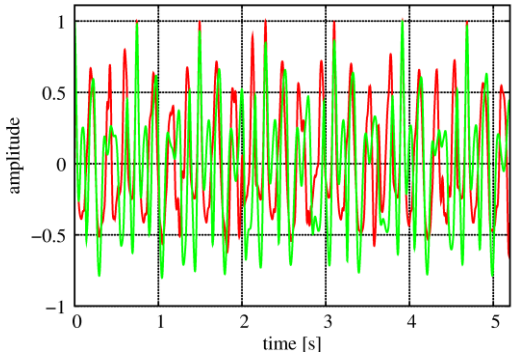

Fig. 3. Autocorrelation functions of ECG (red line) and velocity of heart wall (green line).

Figure 4 shows the standard variation of time differences $\{\tau(p,i)\}$ as a function of interpolated points p. The red line means the standard variation of all time differences $\{\tau(p,n)\}$, and the green crosses show time differences $\{\tau(p,i)\}$ plotted for all heart beats. In this study, the distance between beams at a typical depth of IVS of 50 mm is 5.23 mm. Therefore, the time of propagation of heart-wall vibration between beams is 5.23 ms, if the velocity of propagation is 1 m/s[8]. Therefore, the standard variation of less than 1 ms is considered to be negligible. As shown in **Fig. 4,** for the number p of interpolated points p over 8, the standard variation has the minimum, and the standard variation is less than 1 ms. Therefore, the number of the interpolated points was determined to be 8 and obtained $T_R(i)$ was obtained from Eq. (2).

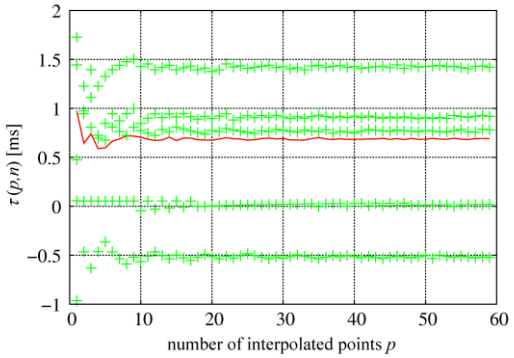

Fig. 4. Time differences $\{\tau(p,n)\}$ plotted as a function of interpolated points.

4. Conclusion

In this report, time difference between the time of peaks of ECG and velocity was investigated. As a result, the standard variation of error was less than 1 ms. Furthermore, we detected the time of R-wave with a high degree of accuracy.

These results showed the possibility of synchronization by ECG to measure the 3D propagation of myocardial contraction and relaxation.

References

1. H. Kanai, Y. Koiwa, Y. Saito, I. Susukida, and M. Tanaka: Jpn. J. Appl. Phys. **38** (1999) 3403.
2. J. D'hooge, B. Bijnens, J. Thoen, F. van de Werf, G. R. Sutherland and P. Suetens: IEEE Trans. Med. Imaging, **21** (2002) 1022.
3. H. Yoshiara, H. Hasegawa, H. Kanai and M. Tanaka: Jpn. J. Appl. Phys. **46** (2007) 4889.
4. Xenophon Papademetris, Albert J. Sinusas, D. P. Dione, J. S. Duncan: Medical Image Analysis **5** (2001) 17.
5. H. Yoshiara, H. Hasegawa, H. Kanai, and M. Tanaka: Jpn. J. Med Ultrason. **34** (2007) [in Japanese].
6. G. R. Sutherland, G. D. Salvo, P. Claus, J. D'hooge and B. Bijnens: J. Amer. Soc. Echocardiogr. **17** (2004) 788.
7. Y. Honjo, H. Hasegawa, H. Kanai: Jpn. J. Appl. Phys. **49** (2010) 07HF14-1.
8. D. M. Bers: *Exacitation-Contraction Coupling and Cardiac Contractile Force* (Kluwer Academic, Boston, 2001) p. 64.