Detection of Temporal Motion Velocity and Acceleration of Omnidirectional M-Mode Echocardiography

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Abstract

Omnidirectional M-mode echocardiography(OME) can detect dynamic information from sequential echocardiography images. Temporal motion velocity and acceleration of a part of the cardiac structure contains the information about the composition of forces related to a heart. In this paper we present methods for detection of temporal motion velocity and acceleration of OME. Gray~time waveforms are rebuilt from sequential images of OME on arbitrary direction lines to track moving structure. Using one-order and two-order differential of the discrete function, temporal velocity and acceleration of one part of the cardiac structure are obtained. The measurement of temporal velocity and acceleration has been applied to 30 clinical cases. Results indicate that along the same direction lines, the velocities measured are not significantly different compared with original B-scan echocardiography.

1. Introduction

Sequential echocardiography images reflect the anatomy border and the motion of the heart in two-dimentional (2D) cardiac section. The reflection of ultrasound waves is used to observe internal structures of the heart. Currently, static image techniques in echocardiography have reached a remarkable level and dynamic information hidden in echocardiography images has drawn more attention in research and clinical diagnosis [1].

There are various ways in which ultrasound information can be displayed [2], including:

- A-mode or amplitude mode: This mode displays the amplitudes of reflected echoes as vertical spikes on a horizontal axis calibrated for distance;
- B-mode or 2D imaging: In this mode, echoes are shown as dots whose intensities reflect the amplitudes of the reflected energy; and
- M-mode or "Time Motion" or TM mode: In this mode, a continuous flow of B-mode images along one dimension is recorded over a period of time.

A-mode is used to assess the depth of an organ, or an organ's dimensions; B-mode provides cross-sections of slow moving or stationary structures, while M-mode is widely used for analyzing moving body parts, and is particularly useful for imaging moving heart valves [3]. It is also one of the main methods for detecting dynamic information from sequential echocardiography images. Typically, an M-mode image consists of a set of wave-beams moving from left to right. The horizontal axis represents the time when ultrasound echoes are received and the vertical axis indicates the distance where the echo occurs. Thus the images provide both temporal and spatial information of cardiac structures. The gray level of any pixel on the image represents the relative strength of an echo received, and therefore provides the boundary information of the cardiac structures. Due to the unique features of heart movement, i.e. motion and distortion, confined and limited ultrasound wave-beam directions in M-mode echocardiography are not able to keep the same movement directions of cardiac structures, therefore, M-mode echocardiography images on the long axis section can be inaccurate. Dynamic information of cardiac structures on an arbitrary direction is then important for the examination of heart motion, which is meaningful for both research study and clinical applications [4].

In this paper, we present our research in detection of temporal motion velocity and acceleration of omnidirectional M-mode echocardiography. We reconstruct gray~time waveforms on arbitrary direction lines from sequential images to track the movements of cardiac structures [5], [6]. Temporal velocity and acceleration information of a certain part of the cardiac structures is deduced based on the gray~time waveforms.

The remainder of this paper is organized as follows. Section 2 presents a description of the OME system, followed by an introduction to the construction of gray~time waveforms. Section 3 describes methods for detecting temporal motion velocity and acceleration of

OME. Section 4 presents representative results and concludes with a discussion of results and future research.

2. Description of the system

2.1. The OME system

Figure 1 illustrates infrastructure of OME system. Sequential echocardiography images are sent to computer to rebuild synchronous ECG signals and gray~time waveforms on arbitrary directions (Figure 2), based on which velocity and acceleration are measured.

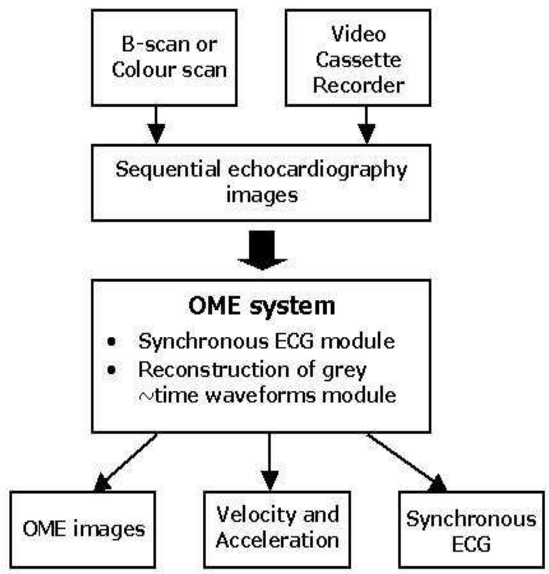

Figure 1. Infrastructure of the OME system

2.2. Reconstruction of gray~time wave-forms

M-mode images are generated by ultrasound wave-beams moving from left to right. As shown in Figure 2, the wave-beam directions (broken lines) are limited, confined, and not aligned with the motion directions. To track motions of cardiac structures, we place direction lines on different parts of the structures, e.g. we place the direction lines A, B and C along the actual motion direction of the wall. The gray~time waveforms are constructed along these lines to track the wall motion.

Let $\vec{r}_i$ be the i^{th} direction line on k^{th} frame of echocardiography image; (x_{ij}, y_{ij}) be the relevant coordinates position of $\vec{r}_{ij}$, pixel (position) j on $\vec{r}_i$; $I(x_{ij}, y_{ij})$ be the gray level of pixel (x_{ij}, y_{ij}), which is also the position of a part of the structure, eg. edge of the wall; and T_{frame} be frame interval time. The movement of a

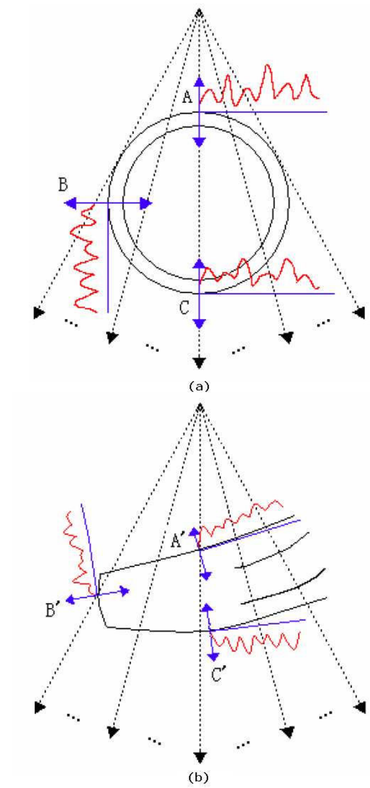

Figure 2. Reconstruction of gray~time waveforms on (a) short axis; and (b) long axis. Broken lines are ultrasound wave-beams; A, B, C; A', B' and C' are the direction lines; and the circles represent the wall of the heart.

certain part of the structure on direction line i can be expressed by gray level $I(x_{ij}, y_{ij})$ at different time t_k, i.e. gray~time waveform, which is defined as follows:

$$I_{\vec{r}_{ij}} = I_{\vec{r}_{ij}}(t_k)\,,\ i = 1, 2, \ldots m; \qquad (1)$$

$$t_k = kT_{frame}\,,\ k = 1, 2, \ldots, n \qquad (2)$$

Since position information along time provides more information than gray level, the above equations can be simplified as follows:

$$\vec{r}_{ij} = \vec{r}_{ij}(t_k)\,,\ i = 1, 2, \ldots m; \qquad (3)$$

$$t_k = kT_{frame}\,,\ k = 1, 2, \ldots, n \qquad (4)$$

The reconstruction procedure is illustrated in Algorithm 1.

Figure 3 shows OME images reconstructed on four directions placed at different parts of the cardiac structures to track motions of each interested part.

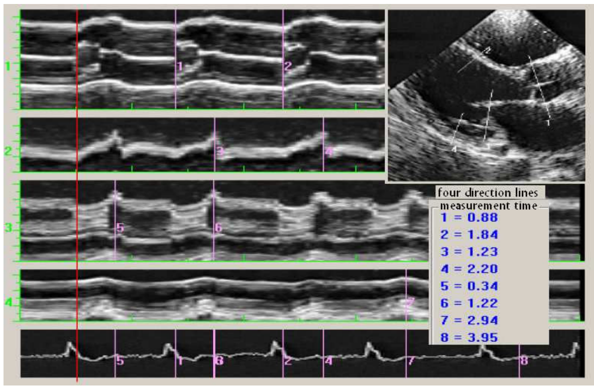

Figure 3. OME images at four directions with synchronous ECG

Algorithm 1. Algorithm for reconstruction of gray~time waveforms

1: **Initialization:** Define the number of sequential images for extracting dynamic information, *n*, and the number of direction lines, *m*

Input *n* frames of images and set direction line $i = 1$

2: **Repeat**

Set the frame number $k = 1$

Repeat

Select a direction line $\vec{r}_i$ on k^{th} frame

Obtain coordinate positions $\vec{r}_{ij}$

Reconstruct gray~time waveform on direction line *i* at frame *k*: $\vec{r}_{ij}(t_k) = \vec{r}_{ij}(kT_{frame})$

Until $k = n$

3: **Until** $i = m$

3. Detection of temporal motion velocity and acceleration

According to kinetic theory, temporal motion velocity and acceleration can be deduced by one-order and two-order differential of gray~time waveforms as follows.

$$\begin{cases} \dfrac{d\vec{r}_{ij}}{dt} = \vec{v}_{ij} \\ \dfrac{d^2\vec{r}_{ij}}{dt^2} = \dfrac{d\vec{v}_{ij}}{dt} = \vec{a}_{ij} \end{cases} \qquad (5)$$

The discrete format of equation (5) is:

$$\begin{cases} \dfrac{\Delta\vec{r}_{ij}}{\Delta t} = \vec{v}_{ij} \\ \dfrac{\Delta\vec{v}_{ij}}{\Delta t} = \vec{a}_{ij} \end{cases} \qquad (6)$$

where $t = nT_{frame}$.

Furthermore, along one direction line, the motion track of a certain position turns into a one-dimensional function of time *t*, which reduces the computational cost. The reader is referred to [5] for more information about the algorithm.

Figure 4(a) illustrates the motion track of a part of the cardiac structure on one direction line, and Figure 4(b) shows the temporal velocity and acceleration calculated from the motion track. The velocity and acceleration curves provide a clear picture of the movement of the structure over time, which may be useful in kinetic study of cardiology.

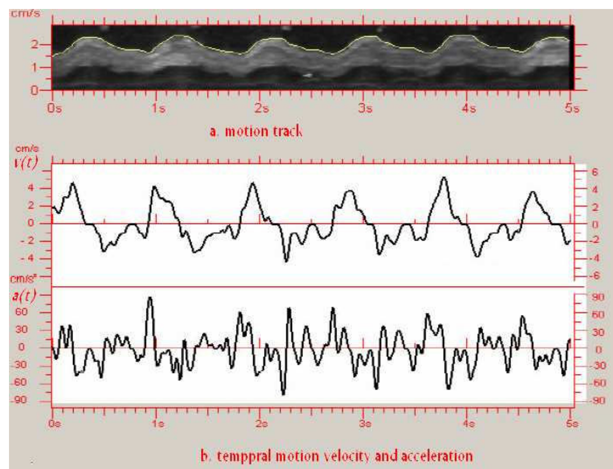

Figure 4. Temporal motion velocity and acceleration detected from one motion track

4. Results and discussion

The OME system developed by Lin *et. al.* [4] has been applied into clinical practice in Fujian Provincial Research Institute for Cardiovascular Diseases and Chinese People's Liberation Army (CPLA) General Hospital (301 Hospital, Beijing) for 3 years. We have compared the measurement of temporal velocity and acceleration in 30 clinical cases. Along the same direction lines, the velocities measured are not significantly different compared with original B-scan echocardiography. Readers are referred to [7-9] for the related research on OME in clinical applications.

Figure 5 shows a classical M-mode echocardiography on original echocardiography. Temporal motion velocity and acceleration of the M-mode Echocardiography are detected and displayed in Figure 6. It illustrates that the proposed method can be integrated with classical M-mode echocardiography in obtaining additional dynamic information of cardiac structures.

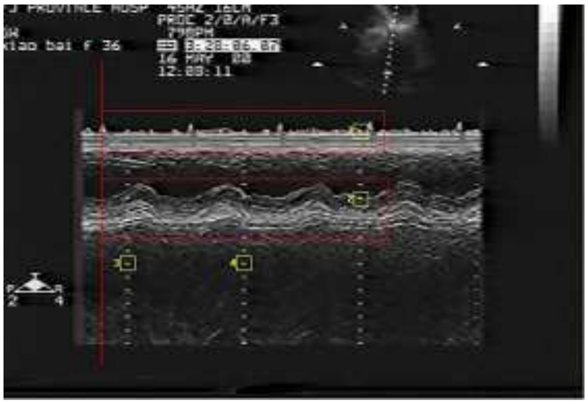

Figure 5. Illustration of one classical M-mode echocardiography

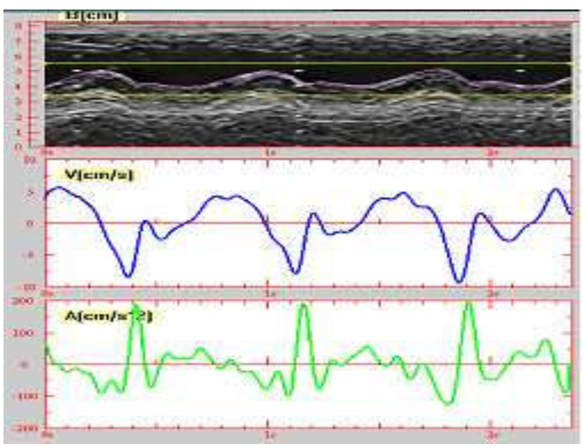

Figure 6. Temporal motion velocity and acceleration of Figure 5.

This paper contributes to the study of mining dynamic information hidden in sequential echocardiography images. The dynamic information of temporal motion velocity and acceleration extracted from OME can be used in studying cardiac medicinal hemodynamics and diagnosing cardiovascular disease atraumatically. Using acceleration, it is possible to obtain the composition of force on certain parts of the cardiac structure during the cardiac periodicity. This deserves further investigation. Another crucial issue is how to apply the dynamic information in clinical diagnosis. This will be an important part of our future work.

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