A Method for Detecting Temporal Motion Velocity and Acceleration of a Part of a Cardiac Structure

Qiang Lin, Yonghua Lin

Biomedical Engineering Institute, Fuzhou University, Fujian Fuzhou, China, 350002

Abstract- This paper introduces a method which detects temporal motion velocity and acceleration of a part of a cardiac structure. We can get motion track of a certain part of the cardiac structure, viz. motional position ~ time function by the waveform curve of Omnidirectional M-mode Echocardiography. Doing one-order and two-order differential of the discrete function, we can acquire the detecting of temporal velocity and acceleration of the part of the cardiac structure. Then, we obtain two important motion information of the cardiac structure in depth, which are velocity ($\frac{ds}{dt} = \vec{v}$) and acceleration ($\frac{d^2s}{dt^2} = \vec{a}$). From Newton's Second Law of Motions ($\vec{F} = m\vec{a}$), we know that the research uncover to acquire the important relating information about the composition of forces of heart through cardiac sequential images. It will be very useful in studying cardiac medicinal hemodynamics and diagnosing cardiovascular disease atraumatically.

Index terms — Omnidirectional M-mode Echocardiography, Mining Dynamic Information, Detecting Temporal Velocity and Acceleration

Ⅰ. INTRODUCTION

Echocardiography images are sequential images reflecting the anatomy border and motion of the heart in 2D cardiac section. Currently, static images in echocardiography have reached a remarkable level. At the same time, the quality of real time motion information is hidden in echocardiography images. This can be used for detecting dynamic information from them.

Echocardiography machines build M-mode echocardiography images with ultrasound wave-beams. It was once the main method for detecting dynamic information from sequential echocardiography images. However, confined and limited ultrasound wave-beam directions induce the inaccurate M-mode echocardiography images on the cardiac long axis section in clinical applications. In addition, the character of the heart, which makes it different from other human tissues, is known as its motion and distortion. For a long time, dynamic information detection of the cardiac structure has been an extremely important exploration and research subject in clinical applications[4]. In addition to dynamic information research on the inaccurate and confined M-mode echocardiography, methods of Blood Flow Doppler Echocardiography (called color scan), Tissue Doppler Echocardiography [5] were also invented and applied into clinical routine.

We rebuild the gray (position) ~ time waveform (function) on arbitrary direction lines from the sequential images. Because the gray level information of the images stands for boundary information of the cardiac structures, the gray ~ time waveform actually represents the stretched movement track of a certain part that is the intersection of anatomy border and sampling line in cardiac structures. The direction of the selected sampling line is consistent with that of the motion, i.e., its first-order differential stands for velocity, and second-order for acceleration. This viewpoint is also an understanding of tissue velocity of the Tissue Doppler. Furthermore, comparing with Tissue Doppler echocardiography, its own characters are illustrated as follows:

- Its velocity comes from the differential of the gray ~ time waveform (function) directly, whereas the velocity of the Tissue Doppler is transformed from frequency shift indirectly.
- Its direction is flexible while the direction of tissue doppler is confined and troublesome.
- The system can show a group of correlative omnidirectional M-mode echocardiography images on arbitrary direction lines with synchronous ECG, which supplies a standard time for the omnidirectional M-mode echocardiography images.

Ⅱ. OMNIDIRECTIONAL M-MODE ECHOCARDIOGRAPHY

The rebuilding of gray(position) ~ time waveform (function) on arbitrary direction lines is a method for tracking the moving object and for mining dynamic information in sequential images[1][2]. When an arbitrary direction line is fixed on a coordinate system, it is ready for a motion range that is smaller and easier to be captured with straight direction line. The target of the echocardiography is the inner cardiac structure. Its size is within several centimeters and each part of the cardiac structure moves between one centimeter and several millimeter. Furthermore, the movement of the cardiac structure is moving back and forth close to the balance point. The dynamic parameters which reflect functional motion are periodic. It can be tracked with a straight direction line, and gray points fixed on the direction line among sequential frames are stretched into gray (position) ~ time waveform (function), which is corresponding to each selected direction line. Then, all mentioned waveforms rebuild series of omnidirectional M-mode echocardiography images.

Rebuilding the gray (position) ~ time waveform (function) on the short axis direction line A,B,C and long axis direction line A', B', C', are illustrated in Fig.1. If the selected direction lines A, B, C and A', B', C' are consistent with actual motion direction of the target part in the short axis or long axis section, when the sampling lines (coordinate position) are fixed, the gray intensity (position) data of the pixels, which come from the image database (memory address and content), can generate gray (position) ~ time waveforms combined with corresponding temporal relationships. They present the movement tracking of the ventricle wall of the cardiac structure. They form the foundation for detecting dynamic information.

Broken lines in Fig.1 are ultrasound wave-beam directions. They are originally confined and limited in direction concerning the B-scan machine for capturing the dynamic information (gray intensity). The actual motion of the cardiac structure is difficult to track exactly in M-mode echocardiography images built by old B-scan machines.

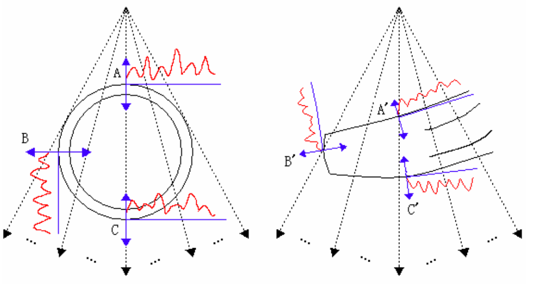

Fig.1 Rebuilding the gray (position) ~ time waveform(function) on short axis (left) and long axis (right)

Ⅲ. THE STRUCTURE AND DYNAMIC INFORMATION UNDERSTANDING OF THE SYSTEM

The overall structure of the omnidirectional M-mode echocardiograhpy system is illustrated in Fig.2. The system is based on the fundamental theory that the gray (position) ~ time function is rebuilt on straight direction lines in sequential images[2][3]. This is combined with the rebuilding technique and adapted hardware.

An appropriative PCI graphics card is employed, which satisfies the transmission speed of 40Mb/s. Provided that one frame has 1 Mbytes data, it is sufficient for transmitting PAL (25 frames/s) or NTSC (30 frames/s) in real time. The block 《Appropriative PCI image card》 carries out the A/D transformation and computer

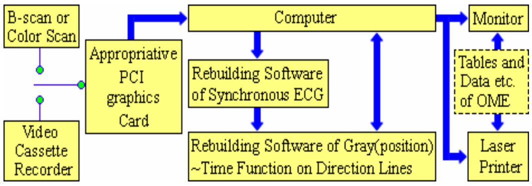

Fig.2 Overall structure of the omnidirectional M-mode echocardiography (OME) system

memory data transmission. It then collaborates with the block 《Rebuilding software of gray (position) ~ time function on direction line》 to capture the gray level and the coordinate information on direction line from the sequential digital frames, which integrates an omnidirectional M-mode echocardiography image. The block 《Rebuilding software of synchronous ECG》 is also introduced. By capturing the cardiogram below the echocardiography images, the software can extract the ECG signal and synchronizes it with the omnidirectional M-mode echocardiography images, to supply a standard time for further processing. Other blocks and common software such as the blocks《Monitor》and 《Laser printer》 are employed to display and print the omnidirectional M-mode echocardiography images, the synchronous ECG and all kinds of dynamic information tables and data.

The most important software component is the rebuilding of gray (position) ~ time waveform (function) on arbitrary direction lines. Its flow chart is illustrated in Fig.3. First block in Fig.3 stands for digital sequential frame-images. Third block is direction line $\vec{r}_i$ which we set in n^{th} frame. Fourth block works out all the relevant coordinates position (x_{ij}, y_{ij}), including series pixels coordinate position (x_{ij}, y_{ij}) where gray level $I_n(x_{ij}, y_{ij})$ exists on direction line $\vec{r}_i$. Gray position function $I_n(x_{ij}, y_{ij})$, which is obtained from the fifth block in Fig.3, represents gray intensity value of point on coordinates position $\left(x_{ij}, y_{ij}\right)$ in n^{th} frame. $I_n\left(x_{ij}, y_{ij}\right)$ varies with independent variable n, when frame interval is defined as T_{frame}, We deduce the function relationship:

$$I_n\left(x_{ij}, y_{ij}\right) \leftrightarrow nT_{frame} \qquad (1)$$

Gray level $I_n\left(x_{ij}, y_{ij}\right)$ and its coordinate position $\left(x_{ij}, y_{ij}\right)$ will also be ascertained once the time nT_{frame} is ascertained. Both function $I_n\left(x_{ij}, y_{ij}\right)$ and $\left(x_{ij}, y_{ij}\right)$ can be expressed with independent variable nT_{frame}. Because coordinate position $\left(x_{ij}, y_{ij}\right)$ is confined on direction line $\vec{r}$, that is

$$\left(x_{ij}, y_{ij}\right) \Rightarrow \vec{r}_{ij} \qquad (2)$$

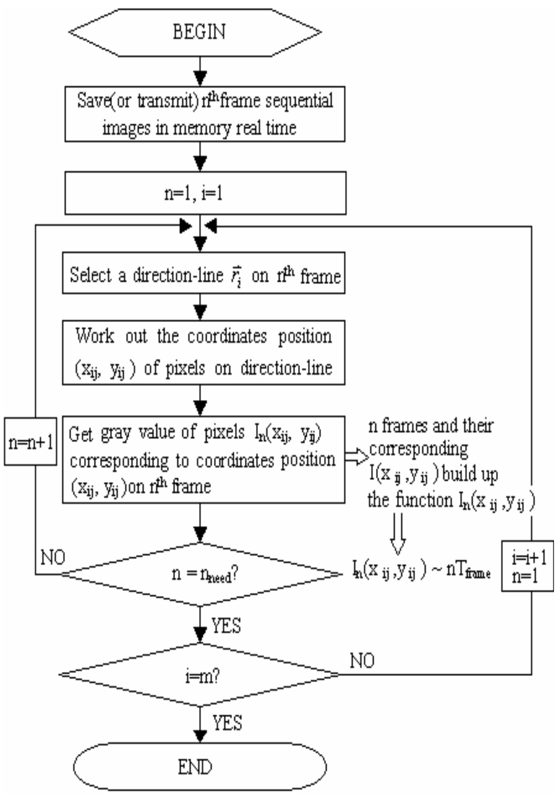

Fig.3 Flow chart of rebuilding software of gray ~ time function on arbitrary direction lines

So the formula (1) and (2) can be translated into an integrated form of gray(position) ~ time function:

$$I_{\vec{r}_{ij}} = I_{\vec{r}_{ij}}(nT_{frame}) \qquad (3)$$

Furthermore, gray (position) ~ time function plays more role than the gray value of pixel in our study, so the above formula is equal to

$$\vec{r}_{ij} = \vec{r}_{ij}(nT_{frame}) = \vec{r}_{ij}(t), \quad t = nT_{frame} \qquad (4)$$

t is discrete time variable sampled with T_{frame}.

$i = 1 \rightarrow m$ stands for motion track of m series of pixels that are corresponding to m direction lines. This is the time function (waveform) form of motion track of sampled pixels, named omnidirectional M-mode echocardiography, on which we detect the dynamic information.

The formula (3) is a gray (position) ~ time function. As illustrated in Fig.4, the system generated four omnidirectional M-mode echocardiography images with synchronous ECG as standard time on four (i.e. m=4) arbitrary direction lines set manually. In the figure, the horizontal axis shows time and the vertical axis shows the gray position on direction line.

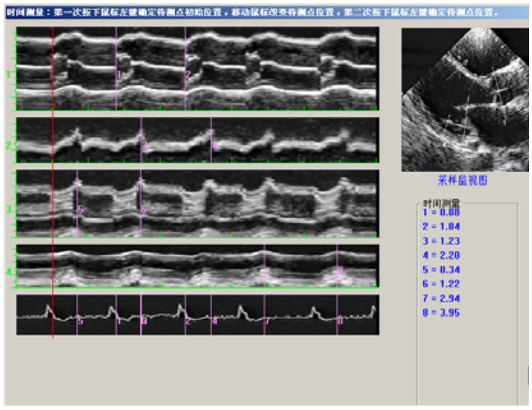

Fig.4 Omnidirectional M-mode echocardiography images with synchronous ECG

Ⅳ. DETECTING TEMPORAL MOTION VELOCITY AND ACCELERATION OF A PART OF A CARDIAC STRUCTURE

The formula (4) described as above translates a form of gray~time into a form of position ~ time function, viz. $\vec{r}_{ij} = \vec{r}_{ij}(t)$. It is the catched motion track of a certain part of the cardiac structure. According to kinetic theory, it will be obtained as follows:

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

And from formula(4) we know that:

$t = nT_{frame}$

viz. independent variable time is discrete variable which is based on T_{frame} .It means time is only the integral multiple of T_{frame}.

One-order and two-order differential of formula(5) can only be differential of discrete function. So the formula(5) can be translated into:

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

$$(\ \Delta t = nT_{frame}\ )$$

The motion direction of omnidirectional M-mode echocardiography is limited on the direction line. The direction we usually modulate manually is the biggest motion direction of a certain part of the cardiac structure. So the motion is along one dimension of the direction line. As shown in Fig.4, it is only along one direction of up(positive) or down(negative). So the formula(6) can be translated into:

$$\begin{cases} S = S(t) \cdots (t = nT_{frame},\ n = 0,1,2 \cdots) \\ \dfrac{\Delta S}{\Delta t} = V(t) \\ \dfrac{\Delta V(t)}{\Delta t} = a(t) \end{cases} \qquad (7)$$

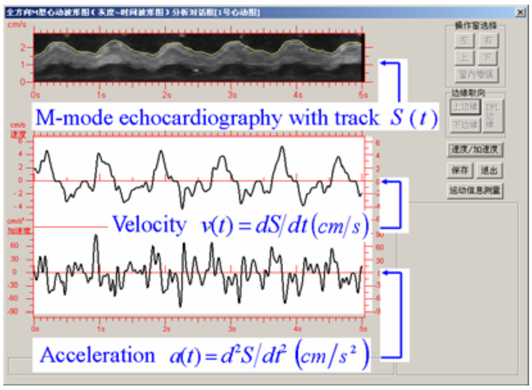

Fig.5 Omnidirectional M-mode echocardiography image with its velocity and acceleration function.

If omnidirectional M-mode echocardiography image of a certain position of cardiac structure is built from sequential images and its edge is detected exactly, the motion track which represents the certain position varying with time will be established as

$$S = S(t)$$

Furthermore, as shown in Fig.5, its first-order differential of time stands for velocity and acceleration of current certain position as formula (7).

Ⅴ. DISCUSSION

The basis of detecting temporal motion velocity and acceleration of a part of cardia structure is the omnidirectional M-mode echocardiography system. The omnidirectional M-mode echocardiography system is an application of rebuilding gray (position) ~ time waveform (function) on relative simple fixed direction line in sequential echocardiography images, it has won the National patents of invention in P.R. of china. The system 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. They summarize the data and the experiments in their own clinical practice according to the function of the system. The related research is mainly on assessment of left ventricle regional systolic and diastolic function, atria septal motion and atria load relation, observation of pulmonary artery motion curve of pulmonary hypertension[6][7][8][9][10][11], etc..

The discussion of this paper is farther detecting viz. detecting temporal motion velocity and acceleration. It ulteriorly mines from dynamic information of sequential echocardiography images. It will ulteriorly and atraumatically open out new dynamic information hided in sequential images. Deduced from Newton Second Law

$$\vec{F} = m\vec{a} \qquad (8)$$

we get the composition of forces function on the current certain position during the cardiac periodicity. Obviously, extraction of $S = S(t)$ is very important, and that is a certain edge of omnidirectional M-mode echocardiography image. When the edge is detected exactly, series further extraction of dynamic information will become possible. The omnidirectional M-mode echocardiography image of sampling position and its motion track $S = S(t)$, i.e. red curve, and its synchronous velocity and acceleration deduced from differential of track are shown in Fig.5, they supply us high-level dynamic information.

However, motion of cardiac structure is complicated and correlative. Furthermore, the motion of ill heart is more complicated and difficult to be comprehended. As a matter of fact, the research we have done is only an initiation; much problem will emerge in the process. On the other hand, the new invented methods and instruments will help to explore the subject in return.

ACKNOWLEDGEMENT

This research is supported by Science Research Foundation of Ministry of Health & United Fujian Provincial Health and Education Project for Tackling the Key Research, P.R.China. (No.WKJ 2005-2-010) and Fujian Province

Major Project of Science and Technology (No.2003I019).

REFERENCES

[1] LinQiang, JiaWenjing, ZhangLi. A Method for Detecting Dynamic Information of Sequential Images－Omnidirectional Gray~time Waveform and its Applications in Echocardiography Images. Proceedings of CISST' 2001, July 2001 in Las Vegas U.S.A, Vol. Ⅱ:760-763.

[2] LinQiang, Jia Wenjing, Yang Xiuzhi. A Method for Mining Data of Sequetial Images － Rebuilding of Gray(Position) ~time Function on Arbitrary Direction Lines. Proceeding of CISST' 2002, June 2002 in Las Vegas U.S.A, Vol. Ⅰ:3-6.

[3] LinQiang, ZhangLi, JiaWenjing. The Realization of Omnidirectional Gray~Time Waveform System and its Application on Echocardiography. Journal of Electrnic Measurement and Instrument, June 2002, Vol.16, No.1: 70-75.

[4] LinQiang. A Detecting Method for contour Based Optical Flow Field of Heart in Ultrasound B-Scan Images. Acta Electronics Sinica, 1996, Vol.24, No.4:122-125.

[5] McDicken WN, Sutherland GR, Moran CM, et al. Colour Doppler velocity imaging of the myocardium. Ultrasound Med Biol 1992: 18: 651-654.

[6] LiYue, WangQing, WenChaoyang. Observation of Pulmonary Artery Motion Curve of Pulmonary Hypertension with Anatomical M-mode Echocardiography. Chinese Journal of Ultrasonography, Oct 2003, Vol.12, No.10: 593-595.

[7] GuoWei, LuLihong, Chenbin. Relation between Atrial Septal Motion and Atrial Load Using Omnidirectional M-mode Echocardiography. Chinese Journal of Ultrasonography, Sep 2004, Vol.13, No.9: 593-595.

[8] LiYue, WangQing, etc. Measuring Left Ventricular Isovolumic Relaxation Time with Anatomical M-mode Echocardiography and Pulsed Doppler. Chinese Journal of Ultrasonography, April 2005, Vol.14, No.4: 271-274.

[9] Lu Lihong, Lin Qiang, etc. Clinical application of Omnirange M-mode Echocardiography — A New Technique, LEJ-1. Chinese Journal of Ultrasond in Medicine, 2001, Vol.17, No.8: 591-593.

[10] LiYue, WangQing, etc. Assessment of Left Ventricle Regional Diastolic Function by Omnidirectional M-mode Echocardiography－Study about a Kind of New Method and Index. Chinese J Med Imaging, 2002, Vol.10, No.3:169-172.

[11] WangQing, LiYue, etc. The Study of Left Ventricle Regional Systolic and Diastolic Function in Normal Subjects by LEJ-1 Omnidirectional M-mode Echocardiography System. Chinese Journal of Medical Imaging Technology, 2003, Vol.19, No.12:1672-1675.