Three-Dimensional Motion Display of Human Heart from Medical Ultrasonic Images

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1 Introduction

Because of the real time processing, the noninvasiveness, the easy operation, the low cost and so on, ultrasonic diagnostic devices are widely employed in clinical use, i.e., visualization of a structure of internal organs and a blood velocity in vessels. Furthermore, two-dimensional(2-D) dynamic images are also obtained with the device and effective in observing the motion of a heart. Since the 2-D anatomical information does not lead to good understanding of the inside structure of organs, three-dimensinal(3-D) presentation have been the key technology for detailed observation of internal organs in medical engineering field. However, as it is difficult that the operator recongnizes a three-dimensional(3-D) structure and movement from two-dimesional(2-D) images sensed by scanning a ultasonic beam, a 3-D visualization technique is expected.

Three-Dimensional visualization technique is developed in the field of computer graphics and some 3-D reconstruction methods are presented in the medical image field, magnetic resonance imaging and computerized tomography[1]-[3]. Indeed, the presentation using computer graphics is suitable to display organs such as a brain and a bone. However, it is difficult to reconstruct a 3-D image from some ultrasonic tomograms because of the following problems; the region segmentation of the poor contrast image, the suitable transform from the pixel to the voxel, and so on.

The rapid progress of computer technology for the last decade promoted the developement of ultrasonic 3-D imaging of fetus and 3-D dynamic imaging of a heart[4], [5]. The image is viewed from the fixed direction and little investigation have been performed on the 3-D dynamic heart imaging from any viewing points.

We have investigated the 3-D dynamic heart imaging using a voxel method and succeeded in observing a mitral valve from any viewing points at about cardiac cycles[6]. However, the surface of reconstructed images is not smooth and the method does not fit detailed observation of the heart motion. Here, we reconstructed the 3-D dynamic heart image using a surface model and improved the above problem. This paper describes the method of the 3-D dynamic heart imaging and experimental resuls.

2 Measurement of Ultrasonic B-Mode Images

Ultrasonic B-mode images covering a mitral valve in a human heart were acquired by a transesophageal probe connected to an ultrasonic diagnostic device(ALOKA SSD870, frequency 5MHz) along longitudinal axis as in Fig.1.

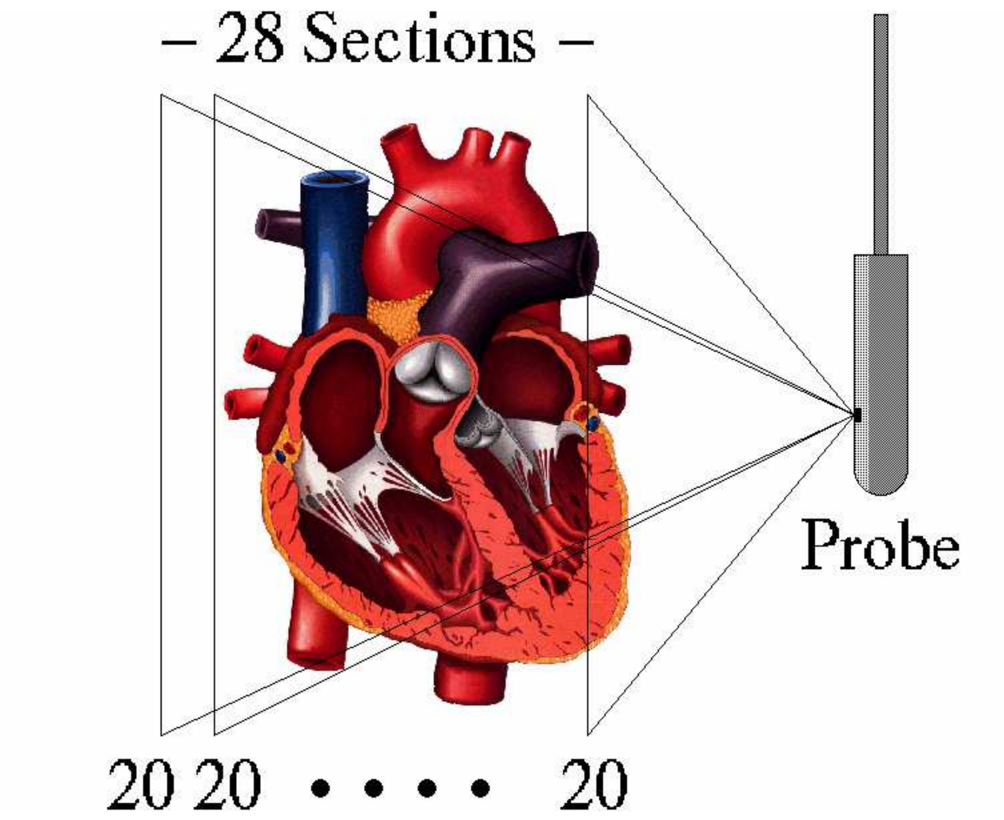


Figure 1: A method of acquiring ultrasonic images. Ultrasonic tomograms are acquired by transesophageal probe.

Twenty B-mode images were measured on a scanning plane during about one cardiac cycle. After that, the scanning plane was rotated at an angle of 2.5degree and 28 images of different scanning planes were measured with synchronizing to an electrocardiography. B-mode images have 320x240pixel and 7bit(128gray scales) as shown in Fig.2.

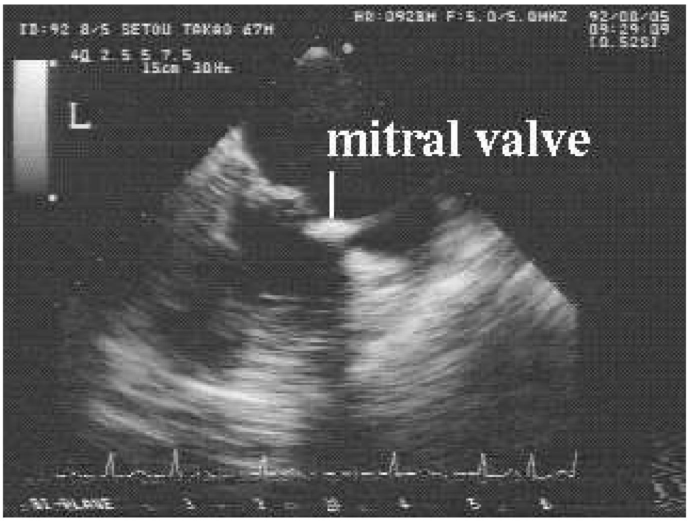


Figure 2: One of ultrasonic heart images. Left atrium is cave on mitral valve and left ventricle is cave under valve.

Totally, 560 B-mode images were stored in a magnetic tape and captured in a graphic work station(SGI ONYX Reality Engine^2).

3 Three-Dimensional Reconstruction

Before performing 3-D image reconstructions every B-mode image was subsampled to an image with 40x30pixel. The subsampled images were divided into 20 groups by the phase on a cardiac cycle and one group consists of 28 subsampled images of different scanning planes.

The method of 3-D image reconstructions was described as follows.

1. The threshold gray scale θ was set to separate the internal and external region of heart.

2. From the coordinates and gray scales of a voxel and the neighboring one, which locate in the opposite region each other, coordinates of points on the surface f were calculated as follows,

$$f = \frac{(g(a) - \theta)b + (\theta - g(b))a}{g(a) - g(b)} \tag{1}$$

   where a and b are coordinates of a voxel and the neighboring one, respectively, and $g(a)$ corresponds to the gray scale of a voxel a.

3. The coordinates-calculation were carried out for the 6-neighboring voxels.

4. Process 2 - 3 were performed for all voxels.

5. The surface of heart was determined by the points obtained from the above processes using Deformed Cubes method.[7]-[9]

Surface normals are unit-length vectors that are perpendicular to a given surface at a particular vertex. Each vertex normals of the surface was determined by relationship vertices position of neighboring vertices. The normals and the defined light source determined colors of vertices. Colors within the surface was estimated with interpolating between the colors at the sampling vertices of the surface. The surface of a 3-D heart image was displayed smoothly with this method.

The dynamic imaging was performed with displaying the 3-D static images obtained with the above method sequentially.

The image reconstruction was carried out on the graphic workstation and it took 10sec to reconstruct 20 3-D static images. The 3-D dynamic image was displayed at a frame rate of 16frames/sec and was viewed from any points in real time by a mouse operation.

4 Results and Discussion

Firstly, the 3-D dynamic heart image was reconstructed for featuring a mitral valve. The 3-D dynamic image was displayed from any viewing points at a cardiac cycle rate and observed the mitral valve motion. Figure 3(a) - (d) are 3-D heart images with at a threshold gray scale $\theta = 24$. Figure 3(a) and (c) are the heart images on systole and (b) and (d) on diastole.

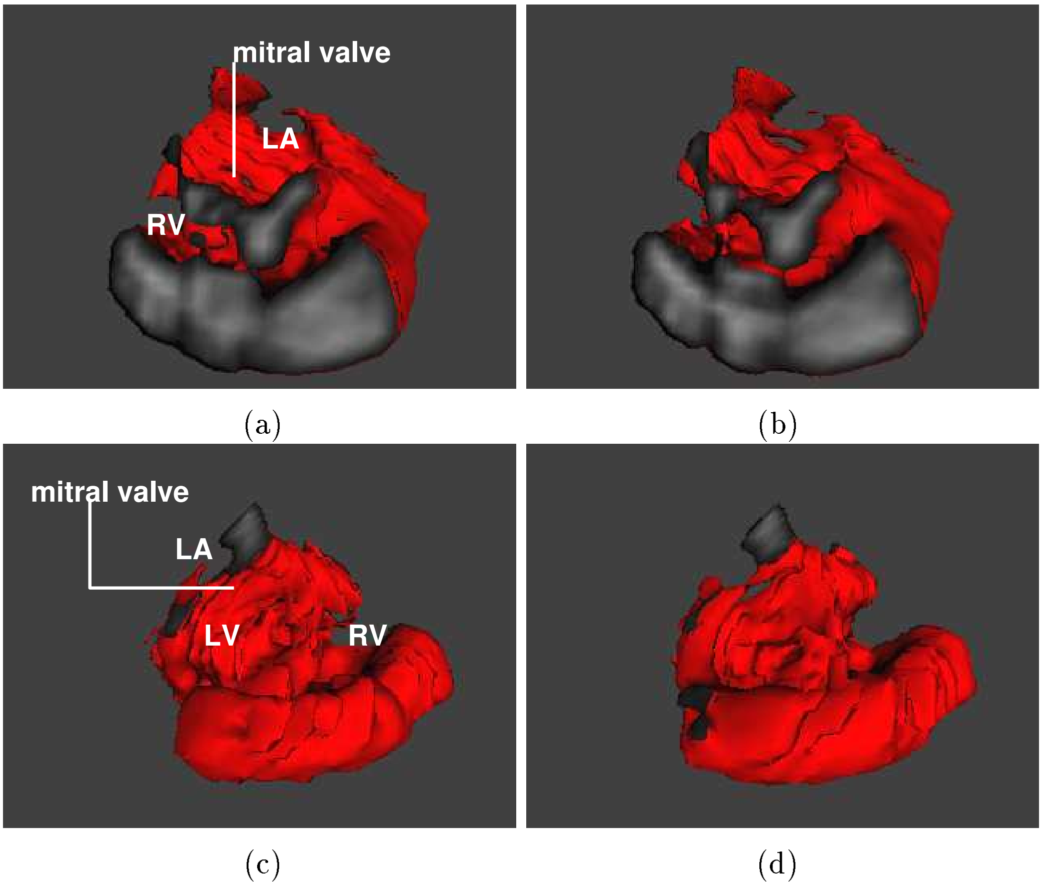
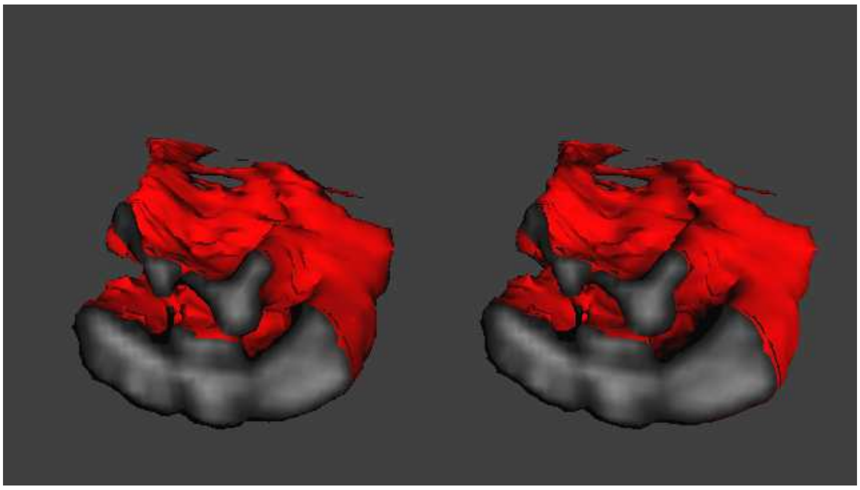


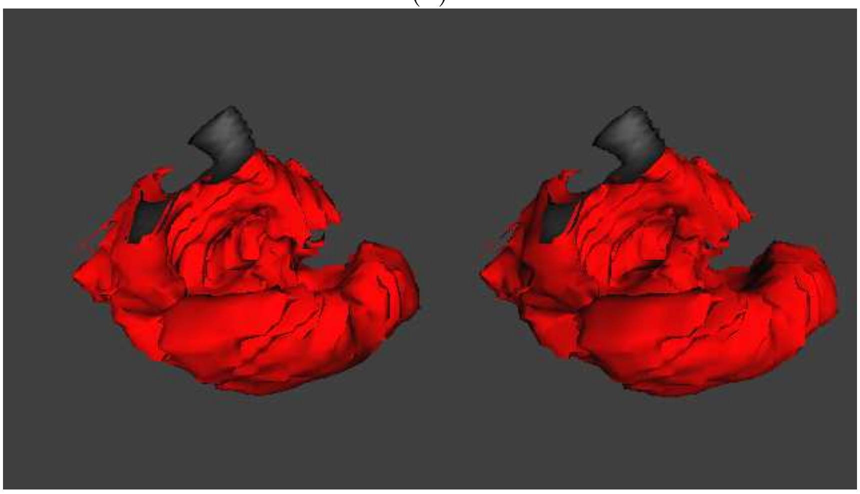
Figure 3: 3-D heart images. Both of end slices in 3-D model are texture mapping of ultrasonic images. (a) and (b) are heart images as seen from left atrium to mitral valve. (c) and (d) are heart images as seen from left ventricle to mitral valve. (a) and (c) are images on systole and (b) and (d) on diastole.

The results show the spatial relationship among mitral valve, left atrium(LA), left ventricle(LV) and right ventricle(RV) separation easy. Furthermore, the mouse operation varying a view point help to understand the structure of a heart. The motion of mitral valve in one cardiac cycle is visualized by animation of 3-D reconstructed heart images. We can easy obtain a 3-D impression of anatomy of heart from 3-D reconstruction images.

Secondly, the stereoscopic dynamic heart image was displayed to enhance the 3-D impression. Figure 4(a) and (b) are the stereoscopic image of a heart on systole. Figures 4(a) is a heart image as seen from left atriume to mitral valve and (b) is from left ventricle to mitral valve.



(a)



(b)

Figure 4: Stereoscopic heart images. (a) is a heart image as seen from left atriume to mitral valve. (b) is a heart image as seen from left ventricle to mitral valve. Both of images are on systole. Please watch the stereograms by method of crossing eyes.

The angular viewing separation between the two images is 0.5degree. The stereoscopic images was also displayed at a cardiac cycle rate from any viwing point by mouse operation. The result provides the sufficient parallax to obtain additional depth cues. The results show better 3-D impression among mitral valve, LA, LV and RV than no stereoscopic images.

This method, which does not need binary images, reconstructs smooth 3-D surface heart images, and is fast calculation time because B-mode images are subsampled to image with 40x30pixel.

5 Conclusion

We proposed the 3-D dynamic heart imaging system using ultrasonic B-mode images obtained from a transesophageal probe. With this system, the 3-D dynamic image viewing from any viewing points was displayed at a cardiac cycle rate and observed mitral valve motion. The 3-D impression of a heart was enforced by the stereoscopic image. Applications of this method are expected for clinical use in respect of fast calculation time of this method and smooth 3-D reconstruction images.

In future, a real-time 3-D ultrasonic tomograms will be useful to visualize the inside structure of a heart.

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