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Comparison of Rendering Methods in Virtual Reality Using Mitral Valve Echocardiography

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Abstract -In advanced medical technology, rendering methods plays an essential role in enhancing the accuracy of mitral valve abnormalities detection and replacement procedures especially in the process of virtual surgery. Consequently, the choice of rendering methods is very much important for real-time visualization of mitral valve echocardiography. This study compares two types of rendering methods in virtual reality visualization: Surface Rendering and Volume Rendering. Specifically, two rendering algorithms including Ray Casting and Marching Cubes were implemented and compared with respect to the rendering speed and interaction. These algorithms were implemented in unity platform to visualize the cardiac echo images in virtual reality. The methodologies, merits and demerits of these algorithms were discussed in detail. Based on the experimental results, rendering method can be determined according to the requirements of virtual mitral valve replacement surgery.
Keywords - Virtual reality, Surface Rendering, Volume Rendering, Echocardiography.

1 INTRODUCTION

With the recent advancements in medical imaging two dimensional image sequences of cardiac images can be obtained in various modalities such as Computed Tomography (CT), Cardiac Ultrasound or Echocardiography and Magnetic Resonance Imaging (MRI). Ultrasound has recently gained acceptance among medical professionals and researchers, particularly in the field of obstetrics, cardiology, and surgical planning, due to the fact that ultrasounds are safer than MRIs and CTs, as well as non-invasive and less expensive [1]. Through the various reconstruction techniques, these 2D images are transformed into three dimensional images with stereoscopic visualization [2]. Meanwhile, through the virtual reality, surgeons can interact with these 3D models and understand the pathological conditions of the cardiac valves and blood flow.

Volume rendering is an essential step for visualization of images in virtual reality [3].Studies such as Hitschrich et al. (2019) [4] and MHPH et al. (2012) [5]demonstrated that direct volume rendering on cardiac ultrasound data can improve task performance in virtual analysis. The recent work [6] highlighted the process of surface rendering for mitral valve assessment particularly in the patients with mitral valve regurgitation. Marching Cube (MC) algorithm was the initial method that provides visual access of rendering [7].Mathias Neugebauer et.al [8]analyzed the behaviour of mitral valve by creating a surface mesh using marching cube method. Max N.et.al [9] proposed various models oftransmission of rays through the different volume intensities by absorption, glow and reflection, which can be applied in rendering algorithm.

The main objective of this paper is to compare the different rendering methods in the aspects of speed and sampling rate on the mitral valve echo data. The work was executed using unity software, which offers better visualization as it supports both surface and volume rendering.

The rest of the paper is organized as follows. Section II depicts experimental platform and datasets used in this analysis. Section III addresses the surface rendering approaches. Section IV describes the mechanism of volume rendering and its types. Section V deals with comparison of rendering methods. Section VI concludes the work summary.

2 EXPERIMENTAL PLATFORMS

The experiment is mainly performed using Unity Software system combined with visualization Toolkit (VTK)[10]. VTK supports software packages and functions for visualization of medical images. For example, in marching cube algorithm [7], vtkMarchingCube class is used. Similarly, in Ray cast rendering method[11] vtkVolumeRayCast class is used. The datasets used in this analysis are obtained from publicly available datasets echocardia[12] and EchoNet-Dynamic[13]. A total of 120 mitral valve echo images from 5 patients were collected in apical 4-chamber (A4C) view. These echo images are affirmed with mitral stenosis pathology [14-15].

3 SURFACE RENDERING

Surface rendering [16] involves the extraction of isosurfaces or edges from the three dimensional volumetric data composed of the two dimensional slices. With the direct surface rendering method, surface of the image is acquired directly from its voxel intensities without any intermediate geometric representations [17]. Transparency and colors are applied to enhance appearance of 3D volume [18]. One of the isosurface rendering method i.e Marching cube algorithm, will be discussed in detail in the subsequent section.

3.1 Marching Cubes (MC)

Marching Cubes focuses on rendering of surfaces from the three dimensional data [19]. The processing pipeline of this algorithm is shown in fig.1. The first step is to determine a voxel value at the eight corners of the cube corresponding to the pixel value.Some pixels have lesser value than the user defined value and rest of the cube have greater value than this value. Next step is to find the edge intersection using these intensities. Finally triangular patches are created using divide and conquer method and by connecting these patches, a smooth surface representation is acquired[20].

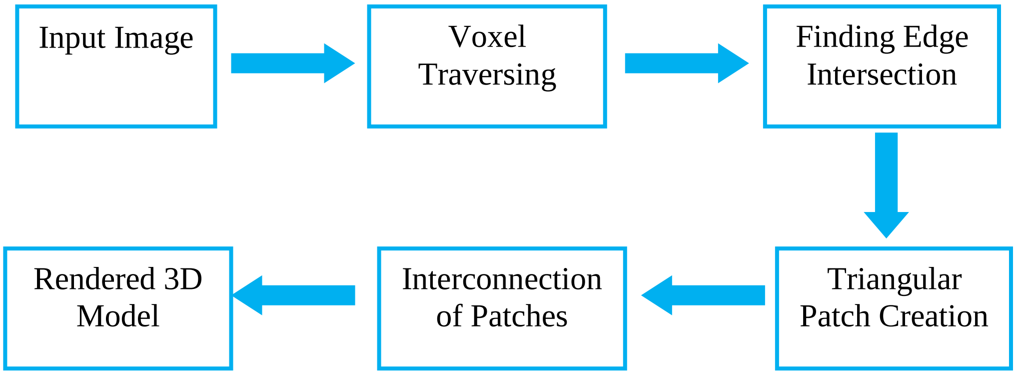

Fig.1 Workflow of Marching Cube Algorithm

The echo images are rendered using the above procedures followed in marching cube algorithm. The images are rendered with four thresholds such as 100, 300, 400 and 800. The rendered cardiac model and rendering time are depicted in fig.2 and Table 1 respectively.

Fig.2Rendered echo model using different threshold ranges (a) Threshold (0,100) (b) Threshold (0,300) (c) Threshold (0,400) (d) Threshold (0,800)

Table 1. Rendering time of echo images using different threshold of the Marching Cube algorithm

Rendering Time in Seconds	Different Threshold Values			
	100	**300**	**400**	**800**
Patient 1	25.21	16.12	9.20	6.85
Patient 2	27.22	15.13	8.15	6.96
Patient 3	26.19	17.15	7.12	6.45
Patient 4	24.17	15.12	9.12	5.35
Patient 5	25.21	16.15	7.15	6.38
Average	25.6	15.93	8.14	6.39

4 VOLUME RENDERING

Volume rendering[21] is based on the principle of projecting three dimensional data onto two dimensional planes by simulating the light rays through the 3D data. During the interaction of volume rendered images, light rays passing through a voxel is directly projected without any intermediate geometric representations. Color and opacity values are assigned by analyzing the voxel intensities[22]. Volume rendering provides the ability to see the underlying structures of the volume slice by slice without discarding any internal details, resulting in an increased visualization effect. One of the main methods of this rendering is Ray Casting that is discussed in the following Section.

4.1 Ray Casting

The illustrative process of ray casting is shown in fig 2. Initially, a ray of data is emitted from the imaging plane depends on the location of the viewpoint. Then these rays are resampled equally at different locations[23-25].Based on the opacity and color value of the neighboring sampling point, interpolation is performed on the voxels. After obtaining the required values of all sampling points, rendered image is visualized.

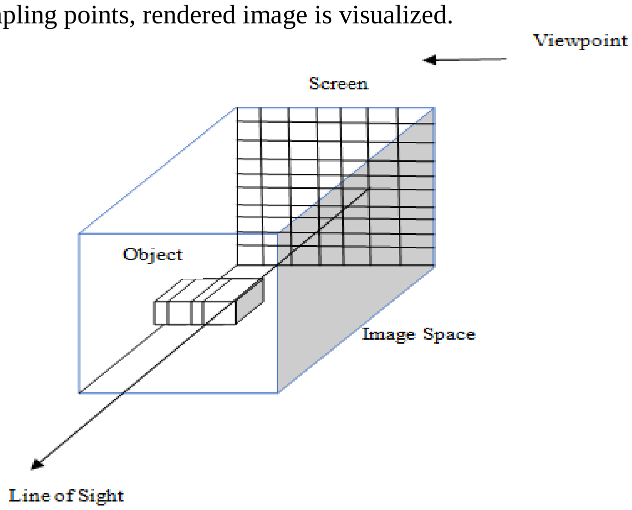

Fig.2 Process of Ray Casting Algorithm

To represent distinct boundaries and underlying structures, different threshold values are defined according to the volume data. It should be noted that color and opacity values are synthesized with the line of sight [26-28]. The experimental results showed that different threshold ranges has a significant rendering effect in visualization of cardiac images (Fig.3) The rendering performance is better when the threshold values are in the range of [0, 1000] as that in the range of [0,400] and [0,800]. The duration of the rendering time is given in the Table 2. From the table it is observed that rendering time does not make much difference for various threshold values. In comparison with surface rendering algorithms, volume rendering is quite better in rendering the echo images in terms of visualization quality.But during the interaction of images, when the angle of view is changed to other direction, correlation between the voxels also gets changed. It is necessary to resynthesize the entire volumetric data again on each time resulting in lack of speed. Fig 4 shows the interactive effect of rotation in volume rendered echo image.

Fig.3 Effect of rendering with threshold ranges (a) Threshold (0,400) (b) Threshold (0,800) (c) Threshold (0, 1000)

Fig.4Interactive Effect (a) Before Rotation (b) During the Rotation (c) After Rotation

Table 2. Rendering time of echo images using different thresholds of the Ray Casting algorithm

Rendering Time in	Different Threshold Values		
	400	**800**	**1000**
Patient 1	6.25	6.12	6.20
Patient 2	6.82	6.15	6.45
Patient 3	6.19	6.35	6.62
Patient 4	6.17	6.12	6.32
Patient 5	6.21	6.35	6.55
Average	6.32	6.21	6.42

5 PERFORMANCE COMPARISON OF RENDERING ALGORITHMS

Rendering algorithms are compared in the aspects of methodology, speed and interaction effect in the above mentioned sections. In terms of methodology, surface rendering creates the intermediate representations of isosurfaces from the 3D volumetric data. Volume Rendering uses the concepts of sampling and projection of rays.

When it comes to rendering speed, surface renderingrenders the image much faster than volume renderingas the volumetric rendering decreases the computational efficiency. As far as the rendering speed, volume rendering creates high quality visualization whereas surface rendering lacks internal structure information and correlation among the voxels.

In terms of human-computer interaction, surface rendering is good compared to the volume rendering. As we do the interactions on rendered image, process lagging emerges from the computation of voxelsampling in the entire image.Table 3 compares the two rendering methods discussed in section 3 and section 4 in the terms of speed, visualization quality and interaction.

Table 3. Comparison of Rendering Methods

Parameters	Surface Rendering (Marching Cube algorithm)	Volume Rendering (Ray Casting)
Speed	Fast	Slow
Visualization Quality	Good	Fair
Interaction	Fair	Good

5 CONCLUSIONS

This paper focuses the rendering methods for visualization of echo images in virtual reality. In comparison of surface and volume rendering methods, Ray casting renders the echo image much better which provides high standard visualization in virtual surgery. Besides, it satisfies the requirements of robotic surgery as the rendering effect is good among the other methods.

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