DEVELOPMENT OF THREE DIMENSIONAL VOLUMETRIC RENDERING IN MEDICAL IMAGE APPLICATION

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FACULTY OF ENGINEERING
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Time passed quickly, my master’s career is coming to an end, and i really feel so honored to study for my master’s degree at Universiti of Malaya. It is short, but everyday on campus and everyone i met is the best memory in my life, i know i will miss my time at the UM, and even start to miss it for now

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Abstract

The distribution, area size, shape, direction, and spatial structure of bones, surface skin, blood vessels and other tissues or organs are the key basis of reference for clinical treatment, diagnosis, and prognosis. On the one hand, due to the continuous development for a long time, the traditional medical images has its unique advantages as the main clinical examination method. On the other hand, the shortcomings of two dimensional (2D) medical images are also obvious: (1). it is difficult for non-professionals to understand complex medical images, which increases the difficulty of doctor-patient communication and treatment. (2). the tissue and organ structure itself is very complex, even experienced professionals will experience misdiagnosis or missed diagnosis due to various factors. (3). there are few professionals with rich practical experience.

Compared with 2D medical images, Three-dimensional (3D) reconstruction medical image is a more clinically practical technical method, the reconstructed image can intuitively display tissues or organs from all directions of point, line and plane. The Visualization Toolkit (VTK) is an excellent and powerful open source software that encapsulates many class libraries to facilitate the realization of 2D to 3D image reconstruction. It is very suitable for use by researchers.

This paper first analyzes the imaging principles and its limitation of CT, MRI,

and ultrasound 2D images, at the same time briefly describe the DICOM medical image standard, the class objects/libraries needed to read DICOM image files in VTK, and the specific implementation steps. Then, introduced the process of 3D volumetric rendering and C++ code on the VTK and visual studio 2008 platform in detail, and focuses on the explanation of the VTK functions that affect the 3D volumetric rendering effect. Next, 3D volumetric rendering is performed using realistic CT brain/head, MRI brain, and ultrasound fetal phantom slices data. Three kinds of medical images were evaluated directly according to the obtained 3D volumetric rendering results, an objective analysis of the 3D volumetric rendering and their corresponding 2D image, as well as the comparison between the three different types of images. The findings of 3D volumetric rendering in three medical image applications are summarized. Finally, in Chapter 5, the development of 3D volumetric rendering in medical images will be discussed in detail.

Keywords: volumetric rendering algorithms, VTK, 3D reconstruction, medical Image

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	:	Two Dimensional
3D	:	Three Dimensional
CT	:	Computed Tomography
MRI	:	Magnetic Resonance Imaging
VTK	:	Visualization Toolkit
NMI	:	Nuclear Medicine Image
T1	:	Longitudinal Relaxation Time
T2	:	Transverse Relaxation Time
T1W1	:	T1 Weighted Image
T2W1	:	T2 Weighted Image
RGB	:	Red, Green, Blue
OpenGL	:	Open Graphics Library
Cmake	:	Cross Platform Make
RAM	:	Random Access Memory
DICOM	:	Digital Imaging and Communications in Medicine
JPEG	:	Joint Photographic Experts Group
BMP	:	Bitmap
DAC	:	Digital-to-Analog Conversion
ADC	:	Analog-to-digital Conversion

CHAPTER 1: INTRODUCTION

Since the term "visualization in scientific computing" was proposed in the last century, the visualization of three dimensional (3D) volumetric data has gradually become a hot research problem in the medical field. Usually, although the medical images we are familiar with only contain three colors of black, white, and gray, there is no problem at all for patients, but it is easy to understand for doctors with professional training, such as CT, MRI, ultrasound and so on. The reason lies in the complexity of medical images. This complexity is not only due to the high similarity of human tissue itself, but also because any subtle changes in the image background will affect the interpretation of the results. The emergence of 3D image display technology has accelerated the development of medical image technology and provided new vision for medical images in diagnosis and treatment. Two-dimensional (2D) images have the defect that they cannot provide pathological details. Therefore, the visualization of 3D medical images does show its superiority in this respect (Brian, 2018). With the advent of the era of digital medical imaging, the application of various possible engineering techniques in medical images has become increasingly mature, which has greatly promoted the development of medical images in diagnosis and treatment. In particular, various optimized medical image processing algorithms have become a key research issue for many researchers. Since 1989, the United States established a virtual human body database that can be arbitrarily cut by researchers, and there has been a large number of researches on the application of 3D reconstruction algorithms in medical images (Zhao, *et al*., 2009). In 1994, Stanford University proposed the Shear-Warp acceleration algorithm with a speed of up to about 1 frame per second, and achieved good 3D volumetric rendering results (Liu, 2013). And in 2000, the University of Vienna tried to merge the maximum density projection method and the direct volumetric rendering method, which also achieved great volumetric rendering results (Hauser, *et al*., 1999). And then laid the foundation for the subsequent research on hybrid algorithms because of the fusion method was proposed. At present, medical image volumetric rendering methods are mainly divided into three classification: surface rendering, volumetric rendering, and hybrid rendering methods. Surface rendering method also can be divided into two types (Zhuge *et al*., 2002): contour reconstruction based on fault boundaries on voxels. It is the earliest developed and widely used rendering algorithm. However, this method is too superficial and not intuitive enough. Thus, the application effect in medical images cannot meet the current needs. Volumetric rendering is to give each voxel an opacity value and a color value, which is divided into two classification (Health *et al*., 1995): image-based space sequence and object-based space sequence. Becasue volumetric rendering can visually display the anatomical details of human tissues or organs, it is a research problem with great research value and potential, and it is also the main research object of this article. The detailed content will be further developed in this article. The hybrid rendering algorithm is one of the most potential solutions for optimizing the volumetric rendering algorithm, and further research is needed. But this article will not elaborate on it.

Volumetric rendering is a 3D visualization medical technology that can be used for non-invasive diagnosis and auxiliary treatment. This technology can directly render voxels in the volume data set by 2D projection of the volume data set without any geometric primitives, thereby developing high-quality volume rendering image (Xing *et al*., 2010). In other words, the essence of volume rendering is to show the details of volume data rather than the surface. In the application of medical images, 3D reconstruction algorithms are often required to accurately reflect the anatomical details of organs or tissues. Hence, this paper mainly focuses on the most representative ray casting algorithm in volumetric rendering as the main research object.

Visualization toolkit (VTK) is an open source toolkit for 3D computer graphics, images processing and visualization. Because of its powerful 3D graphics functions, it has been widely used, and many universities and research institutions use it as a tool for teaching and research (He & Du, 2013). This article will use VTK to perform 3D reconstruction on some 2D medical images (such as CT head images) to obtain 3D medical image models. Since the continuous supplement of VTK can realize a variety of volumetric rendering methods, it has the advantages of ease of development and great 3D reconstruction effect, and it is very suitable for studying the application of 3D volumetric rendering in medical images. Therefore, this paper chooses VTK as the development platform.

1.1 Problem Statement

CT examination is mainly to obtain different slice images after the X-ray layer passing through the human body. The advantage is that the lesion can be observed in multiple directions; the disadvantages are that the accuracy is not high, and the tissue details displayed by the 2D CT image are limited, which is difficult to observe with the naked eye. MRI uses the vibration effect of water molecules in the human body in a magnetic field for inspection. Advantages: Multi-function and multi-parameter imaging, the resolution of soft tissue is higher than that of CT. Disadvantages: there are many restrictions on the patient, and the result is easily disturbed. Ultrasound is to calculate the reflected wave of human tissue to check the condition of the lesion. The advantages is that it can be dynamically observed and the cut surface is arbitrary. And the limitation is that it is more suitable for the inspection of superficial tissues, the detection results of deep tissues are easily interfered by other factors. Based on the understanding of the principles of these three technologies, we can see, the 2D medical images obtained by CT, MRI, and ultrasound are difficult to penetrate deep into the tissue and perform volumetric quantitative detection. They can only be diagnosed after the structural changes in the disease, and once the structural changes are not obvious, it is difficult to accurately detect the lesion.

Therefore, 3D reconstruction of 2D medical images of CT, MRI, and ultrasound are necessary. High-quality 3D visualization of medical images is the focus of many research topics, the 3D volumetric rendering technology is simple and easy to implement. It gets rid of the limitations of traditional rendering technology, and the volume rendering data sets helps to provide clear information about human internal tissues and organs. In addition, there are still problems in efficiency and effectiveness in the process of 3D reconstruction:1). Reconstruction is slow and time-consuming; 2)The reconstruction effect is not ideal, and the extraction of some lesions or tissues is not accurate; 3). Interaction is not smooth; 4). Accuracy needs to be improved.

1.2 Aims

Through the research and analysis of the development of 3D volumetric rendering in CT, MRI, and ultrasound medical image application, the optimization of 3D visualization procedures is realized, and test the accuracy of the results of 3D volumetric rendering technology in the 3D visualization process, and lay a theoretical foundation for the application of 3D volumetric rendering in other medical images.

1.3 Objectives

1) To studies the three dimensional (3D) volumetric rendering techniques used in medical imaging.
2) To design and develop three dimensional volumetric reconstruction algorithm for various type imaging modalities..
3) To evaluate the performance of the developed volumetric reconstruction algorithm.

CHAPTER 2: LITERATURE REVIEW

2.1 Medical images and its limitations

A medical image is composed of a set of basic pixels, which can reflect the internal tissue structure or function of the human anatomical area. The process is to map the gray value to different spatial positions, and represent the discrete image generated by sampling or reconstruction. In other words, medical images can be represented by pixels. In addition, medical images are related with medical image pixel depth, photo-metric interpretation, meta-data, and pixel data (Zhang, 2017). That is, these factors will affect the size and resolution of the medical image directly. Pixel depth (bits) represents the number of bits encoding each pixel, for example: 1 bit depth means that each pixel can contain the value of range from 0 to 1, and 4 bits from 0 to 15. photo-metric interpretation is related to whether the main medical image is colorful or gray. Usually, The number of gray scales is displayed from black to white (0~255). CT images and MRI images are generally gray images. Meta-data is used to represent some other information besides the useful information in the image, the pixel data is used to store the position of the pixel value, and the size of the data represents the size of the image (*Figure 2.1*).

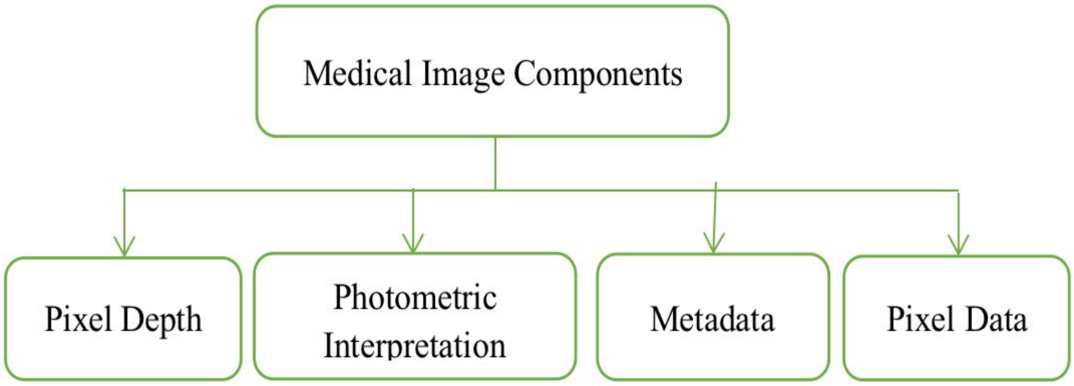


Figure2. 1 Medical Image Components

Medical images are generally classified into functional imaging (CT), magnetic resonance imaging (MRI), nuclear medicine imaging (NMI), and ultrasound imaging according to imaging principles. The following will be divided into three sections to introduce Computed tomography scan (CT), Magnetic resonance imaging (MRI), and ultrasound in detail.

2.1.1 CT images and its principle

Before understanding the principle of CT imaging, it is necessary to understand the imaging process. As shown in Figure 2. CT scans a certain thickness of an anatomical part of the human body with an X-ray beam. The detector receivers the X-ray passing through the layer, After the measured signal is converted into digital information by analog-to-digital conversion (ADC), it is processed by the computer, In this way, get the X absorption value of each unit volume of each layer, that is, the CT value, and then arranged into a digital matrix. These data matrix information can be stored in a magneto-optical disk or tape drive, and then form an analog signal after digital-to-analog conversion (DAC). Finally, after transforming through image processing technology, CT images of human anatomical parts can be observed on the display. This is how the CT image is formed, as shown in Figure 2.2.

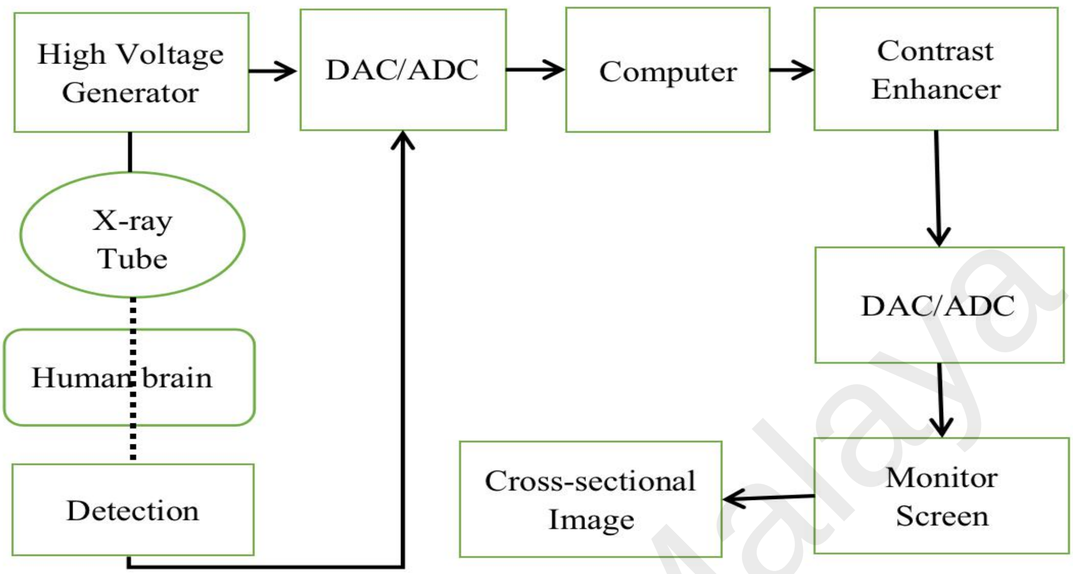


Figure2. 2 How the CT Image is Formed

CT work principle: because the tissues of the human body have different absorption capacities of X-rays, and the resolution of the tissue density are relatively high, according to this characteristics, the CT images are reconstructed and calculated after the X-rays pass through the human body (Kyongtae & Bruce, 2016).

In the CT images, The black part indicates the low X-ray absorption area, such as the lung tissue with air; Gray shadows indicate areas of moderate absorption, such as soft tissues (organs and muscles); The white area shows the high absorption area, that is, the tissue with higher calcium content, such as bone tissue. Compared with traditional X-ray images, CT images have strong spatial resolution and geometrical shapes. The bone images it takes are very clear, which can provide a good position reference for the internal organs, bones, and soft tissues of the human body (Awulachew *et al.,* 2020). Unfortunately, the CT transverse tomography image can avoid the overlap of the tissue structure, but it is not a true anatomical image. The density value measured in the CT scan is only a general statement, not the real tissue density. The limitation of CT examination is that it is not obvious to detect some small lesions (Joaquin *et al.,* 1982*)*. Therefore, CT images cannot effectively observe the spatial structure of all tissues and organs, it can only rely on highly professional and experienced doctors to continuously observe multiple frames of images when examining the lesions, and then integrate it on the doctor's brain to get the diagnosis results. Of course, there are some image processing technology have developing currently for Auxiliary diagnosis, for example, for 2D CT images: Curved planar reformatted (CPR), Movie-frame, Multiplanar reformation (Fu *et al.,* 2020); for 3D CT images: volume rendering technique, shaded surface display, and Maximum intensity projection (Mazziotti *et al.,* 2015). Figure 2.3 shows an example of a chest CT image.

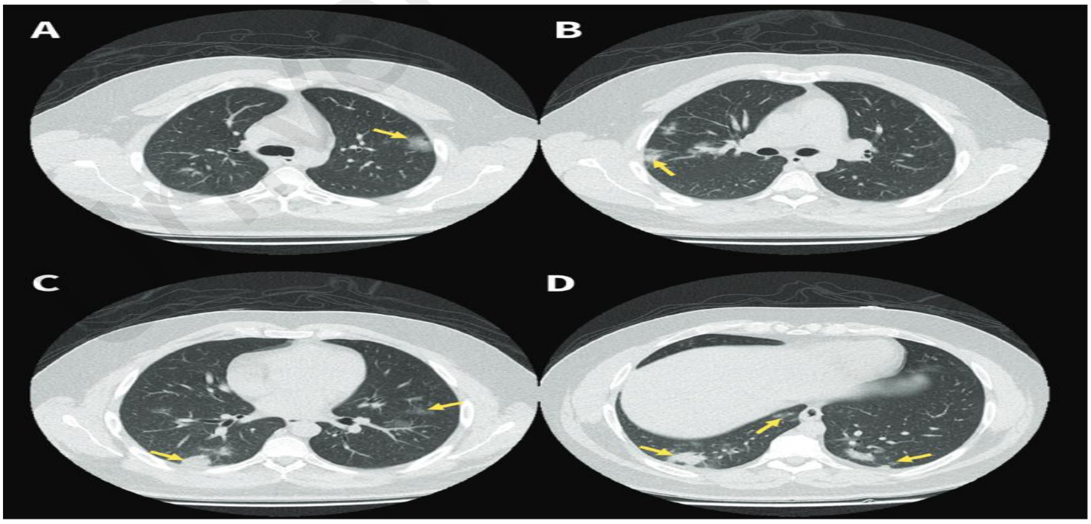


Figure2. 3 Chest CT Images of a 28-year-old Man Infected with Covid-19. it shows the typical lung characteristics of patients with new coronary pneumonia. A and B indicate that increased ground glass density, C and D lesions increase, and lower lobe is round.

Note: this image was retrieved from Case Report. (2020)

2.1.2 MRI images and its limitations.

The imaging process of MRI uses the protons (hydrogen atoms) in human tissues to produce resonance in a strong magnetic field. They will release the absorbed energy in the form of radio frequency signals when the protons are excited. Then the receiving coil is used to capture this signal and perform after processing, finally, the MRI image needed for diagnosis can be obtained (*Figure 2.4*) (Mackiewich, 1995). One the left, (a) indicates that the protons are arranged randomly in the absence of a strong magnetic field. When a strong magnetic field is applied, the protons move around the direction of the magnetic field (b). on the right, the application of a radio frequency pulse causes the proton motion to tilt. When the pulse stops, the protons will return to equilibrium.

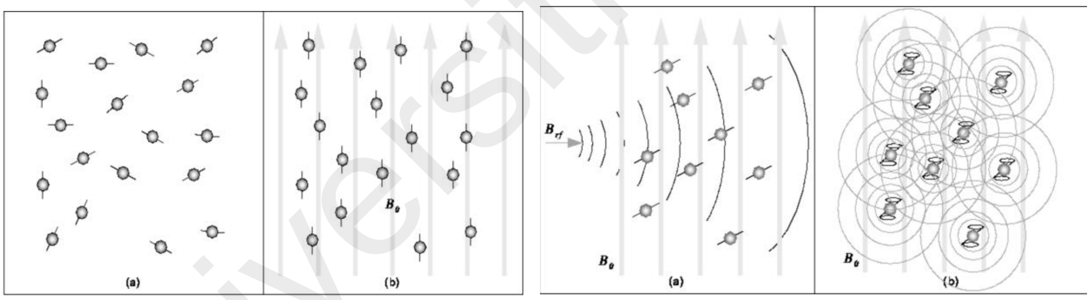


Figure2. 4 Principle of MRI imaging process
Note: this image was retrieved from Basic Principle of MRI. (2019)

Similar to CT images, MRI images are also digital gray-scale images. The difference is that the gray scale on the MRI image represents the intensity of the signal, that is, the length of the relaxation time (the time for the proton spin state to go from unbalance to restoring equilibrium, including T1 (Longitudinal relaxation time) and T2 (Transverse relaxation time)), not the density. MRI has the characteristics of multi-parameter imaging, Because the proportion of water (hydrogen atoms) in human tissue is different, the relaxation time is also different. T1 weighted imaging (T1WI) is usually used to describe the difference in T1 values between tissues. On T1WI, short T1 values are high in signal, such as fat; The long value is low signal, such as cerebrospinal fluid. T2-weighted imaging (T2WI) describes the difference in T2 values between tissues, On the T2WI image, the short T2 value is low signal, such as bone cortex; the long value is low signal is high signal, such as cerebrospinal fluid (*Figure 2.5*). This difference forms signals with different strengths (gray-scale). Observing the strength of this signal that can determine the reference position of the lesion. Under normal circumstances, The stronger the signal of the tissue, the brighter the corresponding part (Gray value approaches 255); The weaker the signal, the darker the image (Close to 0). In addition, in order to enhance the contrast of the signal, a contrast agent such as Ga is usually added. To obtain brighter and easier to observe MRI images (Khetrapal, 2019).

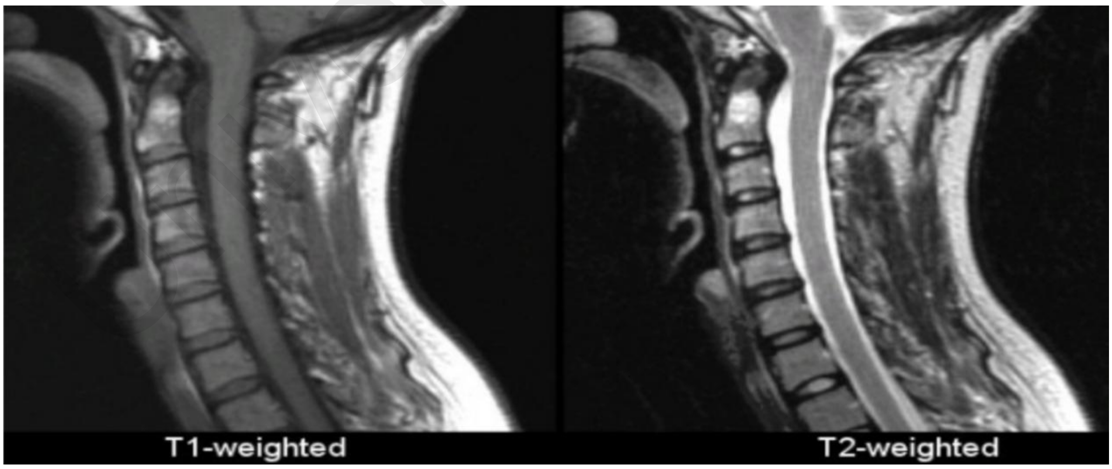


Figure2. 5 A MRI images (brain) from patient

Note: this image was retrieved from MRI basic. (2006)

MRI images are affected by the fluidity of blood, cerebrospinal fluid, etc., so the performance of such signals is complicated. Although 3D images of the brain and spine can be obtained, they are also easily disturbed. To a certain extent, it is difficult to obtain high-quality images.

2.1.3 Ultrasound images and its limitations.

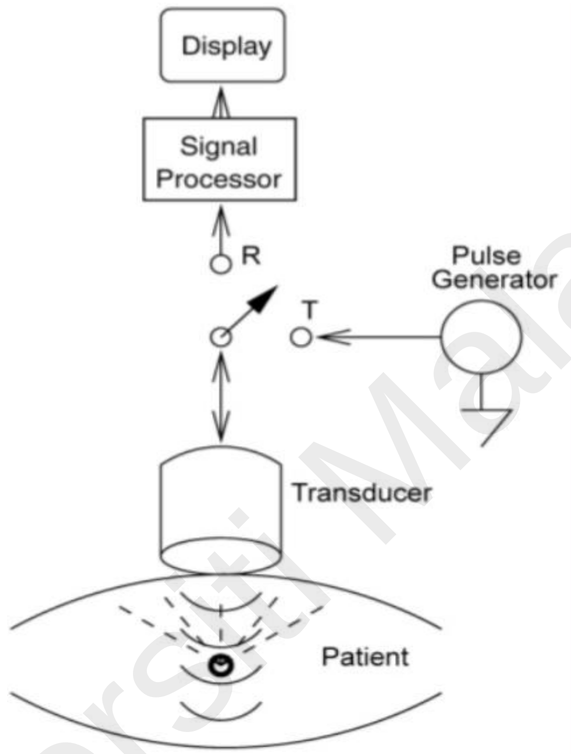


Figure2. 6 The principle of ultrasound imaging

Note: this image was retrieved from Health & Medicine. (2014)

The ultrasound imaging principle is to use high-frequency ultrasound beams to scan the human body, and receive and process the reflected signals from tissues and organs to obtain medical images. When acquiring images, the longer the wavelength of the ultrasound, the better the penetration, and it can detect the heart and other organs well; The shorter the wavelength of ultrasound, the higher the resolution, which can better detect superficial tissues and organs. However, if the acoustic resistance of adjacent tissues is larger than threshold, the ultrasound reflection can hardly be detected. Two-dimensional ultrasound images often fail to show the walls of smaller arteries and veins.

In summary, Essentially, most medical images are still single-channel grayscale images, so 3D reconstruction is necessary (*Table 2.1*).

Table 2. 1 Comparison and summary of three kinds of medical images

Types	**Imaging Principles**	**Features**
CT images	X-ray density projection	2D: Low spatial resolution, artifacts. 3D: Multi-level images can be reconstructed, view the relationship between organs and lesions from multiple angles.
MRI images	Hydrogen nuclear resonance	2D: Spatial resolution is lower than CT. 3D: Can get tomographic images in any direction.
Ultrasound images	Ultrasound wave	2D: limited anatomical range shown, the clarity of organ structure nuclear lesions is not as good as CT and MRI. 3D: high accuracy rate and low missed diagnosis rate.

2.2 Application of 3D reconstruction in medical image

2.2.1 Introduction of 3D reconstruction

3D reconstruction is the process of obtaining a 3D model of the tissue or organ through a series of processing of multiple frames of 2D gray-scale images (medical data) from different angles of a certain tissue or organ (Hanry, 2019). The unique 3D rendering technology can display the real anatomical parts of human tissues or organs on the computer through computer algorithms. It can reduce the risk of using this technique for surgery. Compare with traditional 2D imaging/tomography imaging, 3D medical images that can be zoomed, contrasted, rotated, and observed in multiple spatial perspectives have important clinical use value.

At present, the input of 3D reconstruction not can be only a single image, but also multiple images, and even video streaming. There are different ways to express 3D reconstruction to adapt to various types of images. Such as voxel, point cloud, surface mesh, depth, etc.. Typically, the more the number and details of the input images or videos, the more appropriate algorithms or technologies are selected for processing. 3D medical image visualization technology generally includes volume rendering and surface rendering (Udupa, 1991), this paper will elaborate on volume rendering in section 2.3. Moreover, the platforms that realize 3D reconstruction include Visualization Toolkit, C++, Insight Toolkit, computer graphics, and so on. The study mainly uses the Visualization Toolkit platform and will introduce this platform in detail in section 2.4.

2.2.2 Application of 3D reconstruction

3D reconstruction has many applications in the medical industry, for example, 3D ultrasound can reconstruct the spatial position of blood vessels and the fetal body movements and expressions; 3D reconstruction of CT can display the structure of each layer in real time or near real time; the 3D reconstruction of MRI can not only visually display the target information with simulated color in the lesion area in a short time, but also assist the preoperative examination design of autologous breast reconstruction. Especially in precision surgery and diagnosis application, it provides clinical convenience for all mankind. There are six basic processing methods for 3D reconstruction of medical images respectively: multi-planar reconstruction (MPR), maximum intensity projection (MIP), shade surface display (SSD), curved project reformation (CPR), volume rendering technique (VRT), virtual endoscopy (VE).

- MPR: it is the most basic "3D" reconstruction imaging method and suitable for structural imaging in any plane. Use the thin layer data from the volume in axial CT to observe tissues, organs or lesions at any angle and can show the cross section of the cavity structure. Commonly used to observe the degree of stenos of the cavity and evaluate the invasion of blood vessels (Dalrymple *et al.*, 2005).

- MIP: it projects the highest voxel attenuation value in the largest CT data in a certain thickness (e.g, CT layer thickness) onto the background plane to display all or part of the blood vessels/organs with high enhancement density. Due to the main affect being image by changing the layer thickness, it is often used to create "angiography" images. However, this method will suppress voxels with low tissue or organ attenuation values and overestimates stenos (Sirineni *et al.*, 2006*).*

- SSD: it is the first 3D rendering technology for medical data sets. The intensity of each voxel in the structure of interest can be determined to be within the specified attenuation value range to obtain a 3D view (Paul *et al*., 1999).

- CPR: for bending tubular structures, the process is to select a specific curved path in a certain dimension, and display all the voxels on the path on the same plane. It is beneficial to the examination of blood vessels, pancreatic ducts, spine, and arteries (Williams *et al.,* 2008).

- VRT: can describe complex tissue/organ structures more clearly, it is powerful, realistic in shape and color, and conductive to the 3D modeling of arteriovenous blood vessels and bone structures. It is also the focus of this paper (Choe *et al.,* 2001).

- VE: assuming that the line of sight is in the "cavity" of the tube to be observed, the range of cross-sectional images obtained in 3D space can be magnified by setting a series of parameter ranges (Vagli *et al., 2008*).

2.3 3D Volumetric rendering technology and key concepts

2.3.1 3D Volumetric rendering technology

Due to surface rendering technology will lose the dimensional of the information when visualizing volume data (Kaufman & Mueller, 2005*)*. Hence researchers proposed volumetric rendering to make up for this shortcoming, volumetric rendering is a method that can obtain in a 3D data set and then project it to 2D, this method can generate an overall image of three-dimensional data, include every detail, and has the advantages of high image quality and convenient parallel processing. There are many techniques that have been developed to render volume data now.

2.3.1.1 Volumetric data

Voxel (abbreviation for volume pixel) is the smallest unit in 3D space division, it can be understood as a dot for a small area with arrangement and color in a 3D space. Likewise, we can also think of medical images as being composed of a voxel. The typical 3D data set is a set of 2D slice image data obtained by arranging medical volume data (such as CT, MRI) on a Cartesian voxel grid (*Figure 2.7*) (Bernhard & Charl, 2014*)*. These images are usually acquired using regular patterns (for example, 1 slice per millimeter) and use trilinear interpolation to calculates the value between grids.

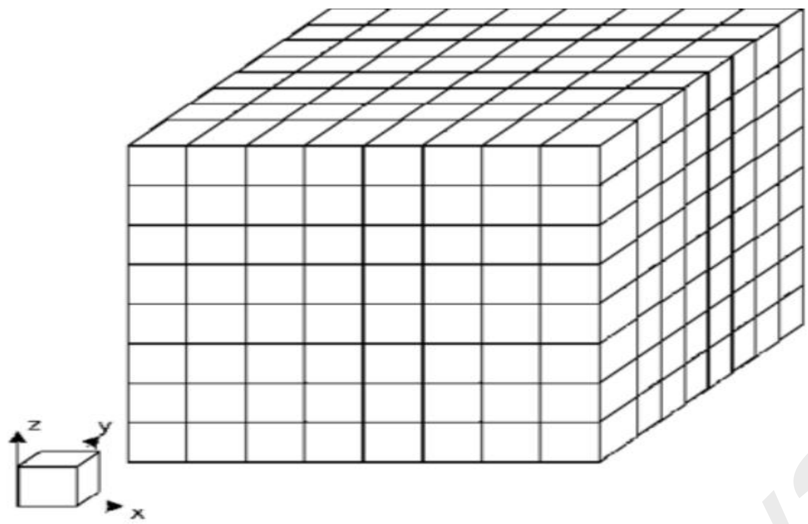


Figure2. 7 Cartesian grid

Note: this image was retrieved from Visual Computing for Medicine. (2013). Second edition. https://www.sciencedirect.com/science/article/pii/B978012415873300002X?via%3Dihub

The 3D volumetric rendering data representation: block/regular grid, implicit 3D function, an atlas composed of index bricks or blocks of the original data set, and point cloud.

2.3.1.2 Volumetric rendering methods

There are different methods used in volumetric rendering, such as : ray casting, texture slicing, re-sampling, and splatting. The following mainly introduces the ray casting method.

Ray casting is the most commonly used algorithm in volume rendering (zhao *et al.*, 2020). The basic principle is: emit a radio-graph along a fixed direction or observation direction for each pixel of the output medical image (*Figure 2.8*), as the light travels through the entire image sequence, the image sequence is sampled to obtain color information. Here usually use RGB (R=red, G=green, B=blue) to define the opacity and color of the voxel. Then accumulate the color values according to the light absorption model until the light travel end. Finally, the obtained rendered image is displayed on the screen, and the 3D rendered image that we want and easy observation is obtained. The objective of ray casting is to maximize the use of 3D data without imposing any additional effects on the data. There are two main ray casting methods: a). Blinn model; b) Kajiya model.

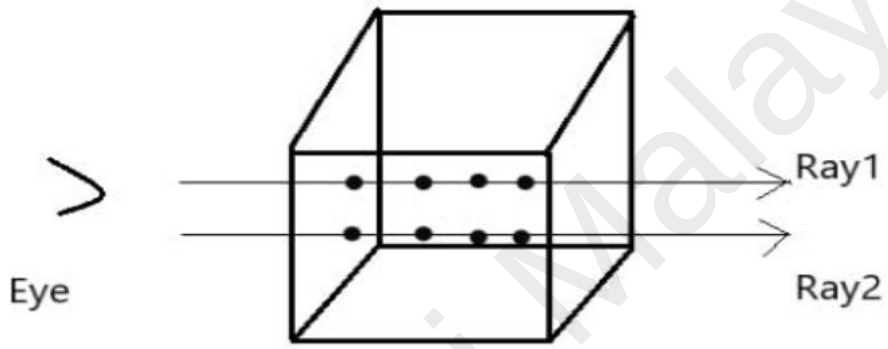


Figure2. 8 Principle of Ray Casting

The ray casting needs to classify the data values of the 3D medical data field and given the color value and opacity value, then project from the 2D projection along each pixel of the image, and the subject data field of each ray intersects the intersection of the image, in the end, color re-sampling through interpolation and the color of sample points and opacity values. As shown in Figure 2.9, providing a high opacity value to obtain the external structure, and lower the opacity value to help visualize the internal structure (Kalshetti *et al.,* 2018).

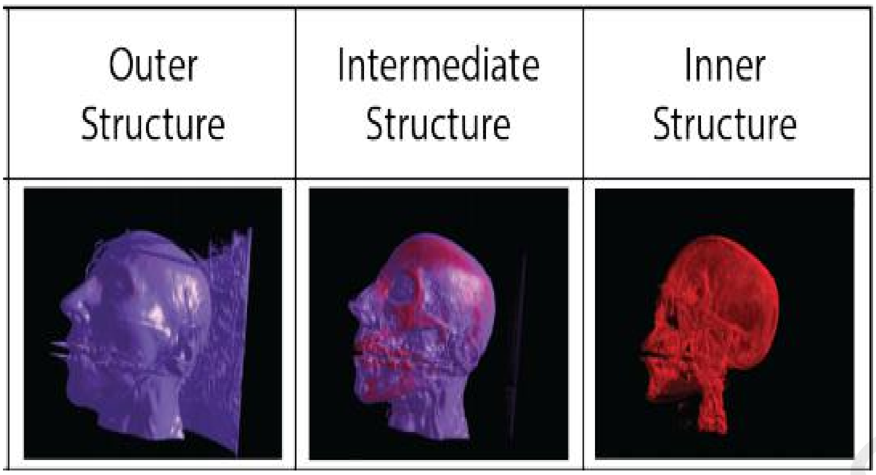


Figure2. 9 Brain CT volume rendering image

Note: this image was retrieved from Computer Science: Graphics. (2018).

The main purpose of data classification is to map the scalar value of volume data to color and opacity. The flow chart of the algorithm is as follows (Ma, 2019).

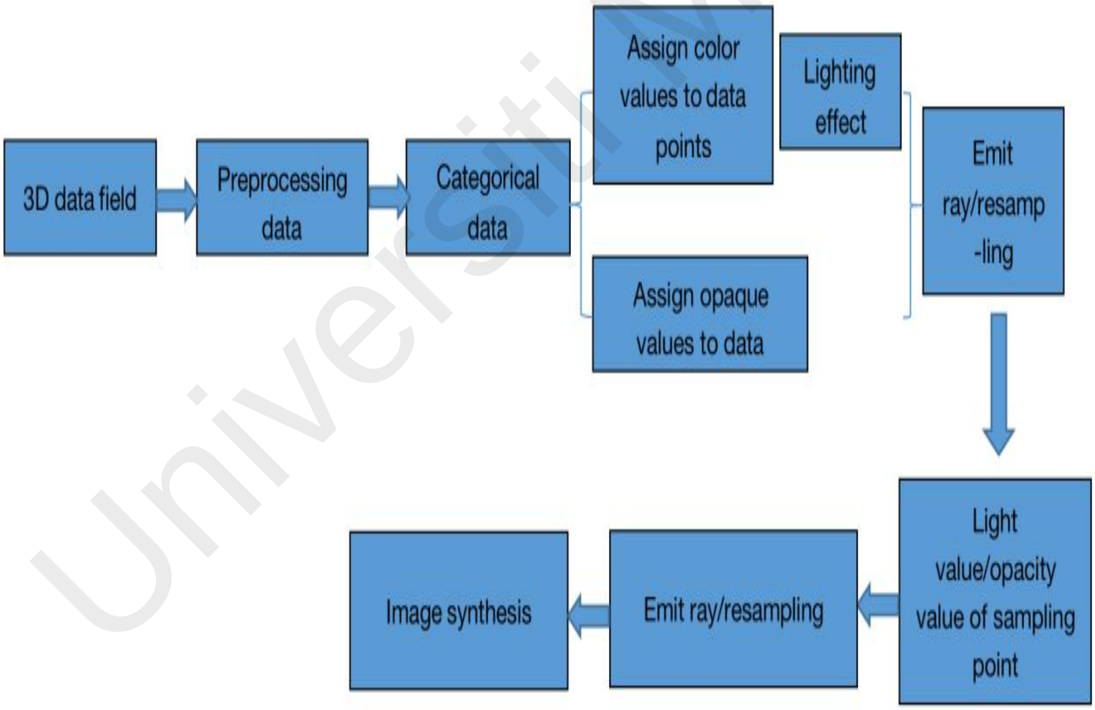


Figure2. 10 The flow of ray casting algorithm

2.4 Visualization Toolkit (VTK) in 3D medical images

2.4.1 What is Visualization Toolkit?

In 1993, Schroeder and his colleagues (Schroeder *et al.*, 2000) wrote a "visualization toolkit" (that is, an object-oriented 3D graphics method) supporting software. This is the origin of visualization toolkit (VTK), after other researchers expanded and repeatedly modified the content of the software, it finally became mature. VTK is a free and open source software system, it is portable and commonly used for 3D medical image visualization and image processing, and supports C++, Python, Java, TCL and other programming languages. VTK provides a variety of data representations, such as polygon data, images, straight lines, and unstructured grids. To render medical images in VTK, polygonal, texture-based, 2D and other methods can be used alone or in combination.

The core of VTK is mainly built by C++, there are more than 2000 classes, several conversion interfaces, and about 250,000 lines of code, its features are as follows:

a) It has powerful 3D graphics functions. VTK supports both volume rendering and surface rendering, while making full use of the existing graphics library and graphics hardware, it can also improve the visualization of 3D graphics.

b) VTK is independent of any GUI at the core layer and does not depend on a particular window. During the use process, application developers can easily insert VTK into their own development system.

c) It can be compatible with both Windows operating system and Unix operating system at the same time, and the code is portable due to its device-independent characteristics.

d) It has the ability to cache data and excellent streaming.

e) The interior includes two main subsystems, the graphics model subsystem and the visualization pipeline subsystem.

2.4.2 VTK volume rendering

Use vtkVolume in VTK to represent rendering objects, it also stores vtkAbstractVolumeMapper objects and vtkVolumeProperty objects inside. The role of the vtkAbstractVolumeMapper object is: obtain primitive data through volume rendering algorithm. And the vtkVolumeProperty objects function is to set the parameters of the color and opacity function. To achieve volume rendering, a corresponding pipeline must be set in the VTK visualization data (Anand, 2018), as shown below:

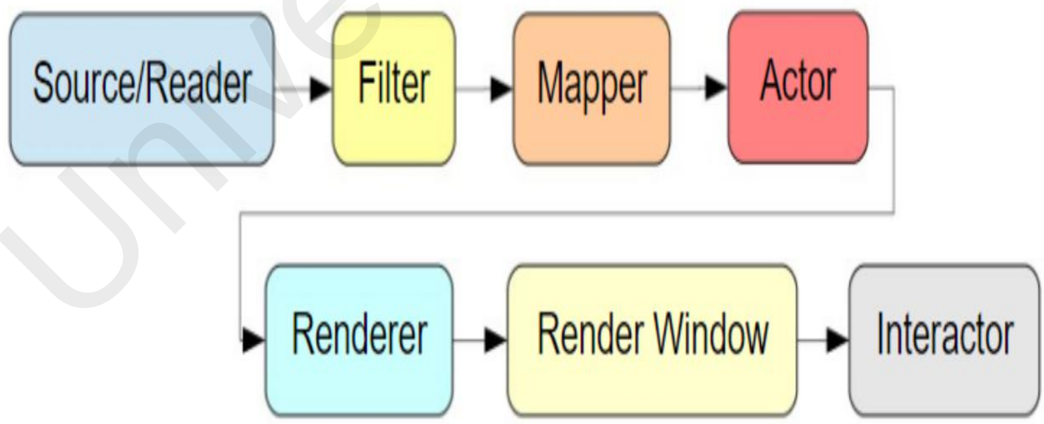


Figure2. 11 The pipeline

➢ Source/Reader: the medical images data from stored files, such as CT head images, brain images, MRI cardiac images, spine images, echo-cardiogram, and so on.

- Filter: a certain algorithm is used to modify the size, density or intensity of the selected medical image data.
- Mapper: map medical data to the renderers vtkPloyDataMapper and vtkPolyDataMapper to display graphics primitives, such as points or lines.
- Actor: use vtkActor to represent objects in the rendered scene, such as attributes of medical images: position, direction, scale etc.
- Renderer: use OpenGL (Open graphics library) for rendering in VTK, and use vtkRenderer to control the rendering process of actors and scenes.
- Render Window: create this window for rendering.
- Interactor: mainly use for interaction.

2.4.2 The application of VTK in 3D reconstruction

VTK provides a faster and more accurate method for developing 3D models of medical images. we can use the mouse in the virtual environment of VTK to move, rotate, and zoom objects (Huang *et al.*, 2011), so that can find the target point of observation from the spatial position.

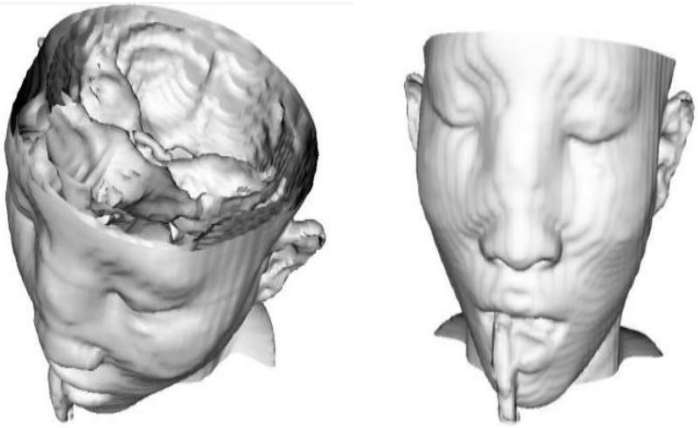


Figure2. 12 The Scene of Head 3D Image (no color and opacity value be added)

After simple modeling as shown in Figure 2.12. it can clearly see the 3D head model, but can not see the blood vessels, bones, and skin.

(a). 3D CT head images based on VTK.

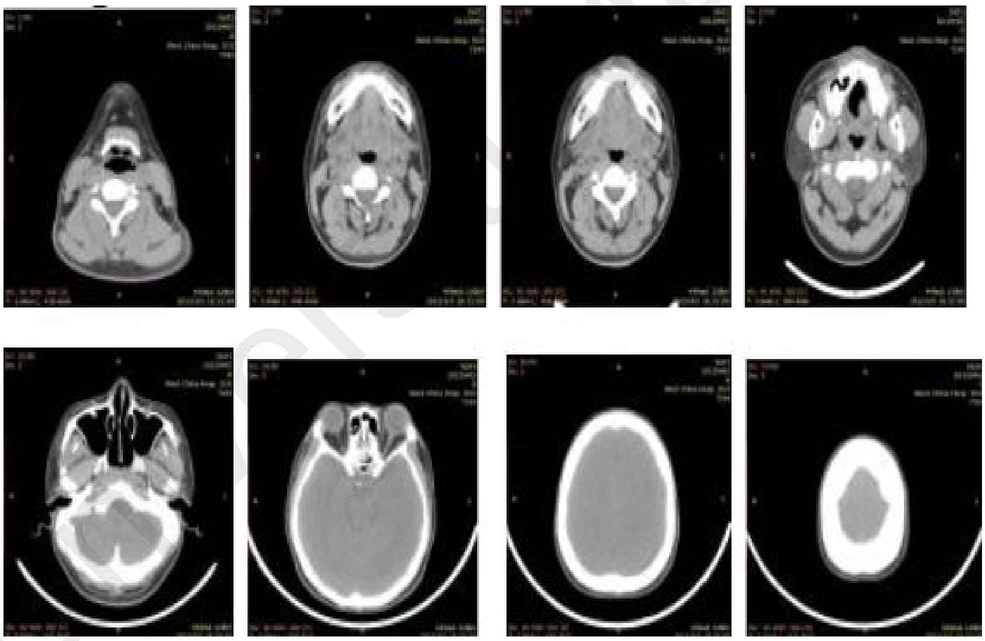


Figure2. 13 The CT Head Image Data

Note: this image was retrieved from ICARM (5th International Conference on Advanced Robotics and Mechatronics).(2020)

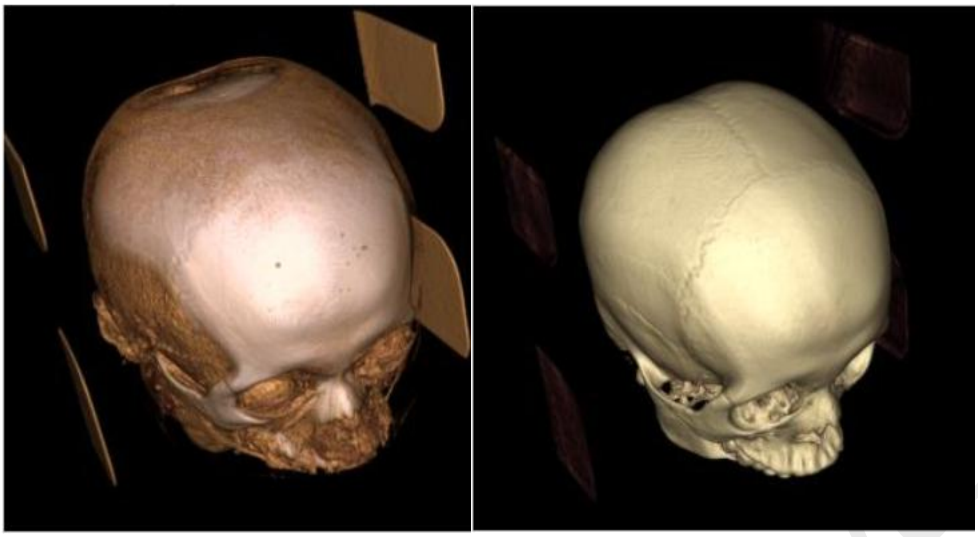


Figure2. 14 CT Head Image with Volumetric Rendering. the left one shows before rendering, and rendered on the right.

Noted: picture for CT head rendering image from.

(b). 3D MRI abdomen images based on VTK

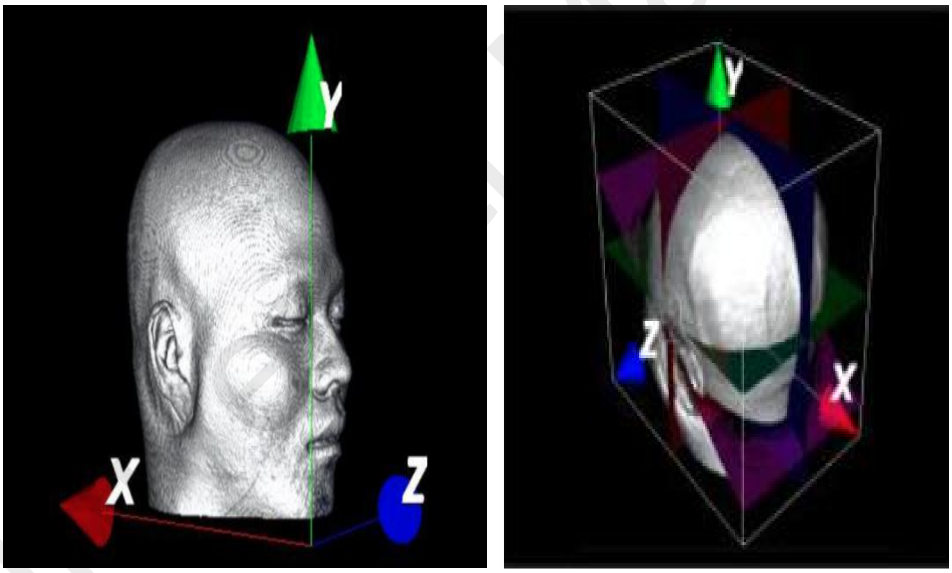


Figure2. 15 3D Reconstruction of MRI Head Image. use vtkVolumeRayCastMapper order

The anatomy can be observed from multiple angles, it is a 3D reconstruction model without adding opacity and color values.

(c). 3D ultrasound infant images based on VTK (Mahani et al., 2011)

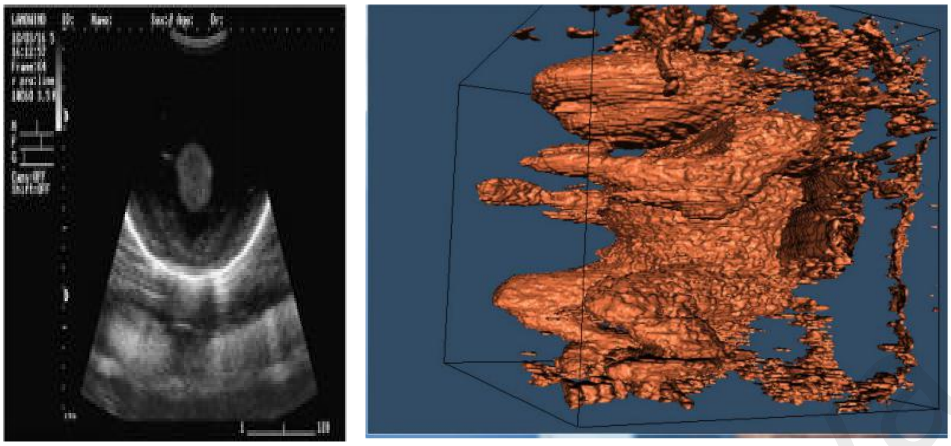


Figure2. 16 3D Reconstruction of Fetal Ultrasound Image use VTK. On the left, it is original image. On the right, it is the result after 3D reconstruction.

Note: this image was retrieved from 9th WSEAS International Inference on Signal Processing. Malaysia: University of Malay. (2010)

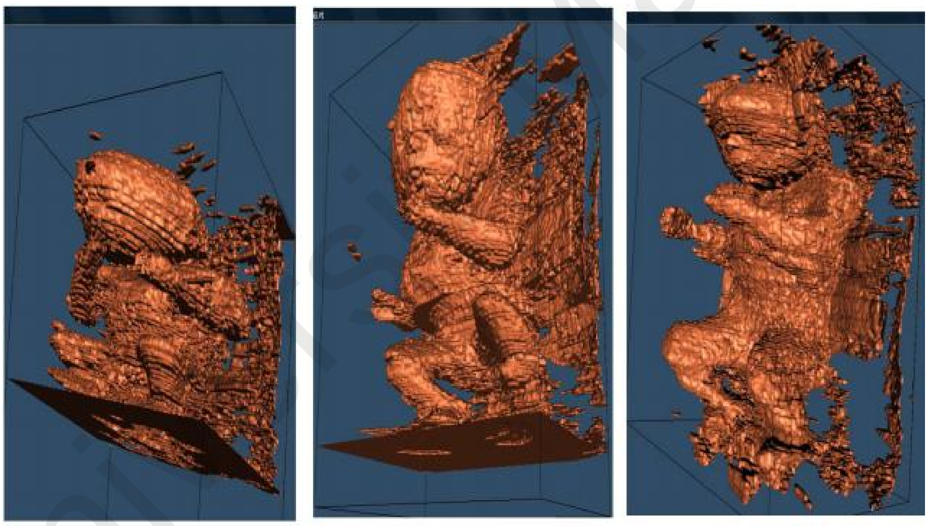


Figure2. 17 Results After Reconstruction with Different Slice Number. On the left, slice number is 103, middle is 155, and the right one is 183

VTK is a powerful library of medical imaging algorithms. Volume rendering technology can improve the perspective of medical images. However, in order to obtain more realistic three-dimensional images, it is best to select more slices.

2.5 Image data format

Images generally come in many formats, different image formats usually derived from different imaging device/equipment or principle. Medical images contain a large number of complex structures of tissues or organs, and its storage mode is also relatively high. In medical field, the most widely known images are CT, MRI, and ultrasound images. At present, most of the images data after reconstruction of CT, ultrasound, MRI and other equipment are stored in DICOM format, this format contains a large amount of medical data set information, which meets the needs of clinical data exchange. Therefore, it is regarded as one of the most commonly used standards.

JPEG format is the earliest standard used for image compression, it supports a wide range of applications with very advanced compression technology, so it has been successfully applied to the Internet and digital cameras in just a few years.

Compare to DICOM and JPEG, BMP format is a uncommon format, it is often scans the image line by line from the lower left corner of the image, and records the pixels of the image one by one. This format image does not compress the image data, so the stored color is accurate. In most cases, when processing medical images, DICOM is often converted to BMP format, so that DICOM format can be better displayed. A simple comparison is shown in Table 2.2.

Table 2. 2 Sample comparison of image formats

Images File Formats	**File Extension**	**Advantages**	**Disadvantages**
DICOM	.dcm	✓ Enhanced patient safety (images and data kept together). ✓ Single network transactions will transfer both image and patient details.	If optional fields are added to the file but not filled in correctly then that could cause image objects to be incomplete and cause issues.
JPEG	.jpg or .jpeg	✓ High compatibility. ✓ Widespread use. ✓ Full color spectrum.	a. No layers b. Lossy compression c. Doesn't support transparencies and animations.
BMP	.bmp	✓ Simply structured. ✓ An integral part of Windows. ✓ Large structured.	Big file outputs even after compression.

Note: source by IONOS website with no author: Image file formats: An overview of 10 image file types (2021).
Retrieved from:
https://www.ionos.com/digitalguide/websites/web-design/image-file-format-types/

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1 Experimental Environment and Materials

3.1.1 Environment Configuration

Application Tools:

- ✓ Visual Studio 2008 (C++)
- ✓ CMake (Cross platform make) 2.8
- ✓ VTK-5.6.1, VTK Data-5.6.1

PC Configuration:

- ✓ Processor: Intel(R) Core(TM) i5-1030NG7 CPU @ 1.10GHz
- ✓ RAM (Random access memory): 8GB
- ✓ Display resolution: 2560x1600
- ✓ Version: 20H2 Windows 10

3.1.2 Materials

Prepare 2D medical images (slices) as follows:

- ✓ CT head images
- ✓ MRI brain images
- ✓ Ultrasound fetal images

3.2 Medical Image Data Acquire

This paper will use 2D medical image data standard formats of DICOM and JPG, The original image data obtained from CT is 89 DICOM head images and 25 JPG brain images with a resolution of 1012x706, the original image data obtained from ultrasound is 223 JPG fetal images, and the resolution is 963x768. The number of images obtained from MRI is 25, and the resolution is 236x236 JPG brain images.

3.3 Volumetric Rendering Realization

3.3.1 Realization of read image data in VTK

VTK can read diverse forms image data, such as DICOM, BMP, JPEG and so on, this paper mainly use JPG and DICOM standard medical data, it will use the reading function encapsulated by the vtkDICOMImageReader class library provided by the VTK class library when use VTK to read the required CT DICOM head image data, its reading process is shown in the following flowchart.

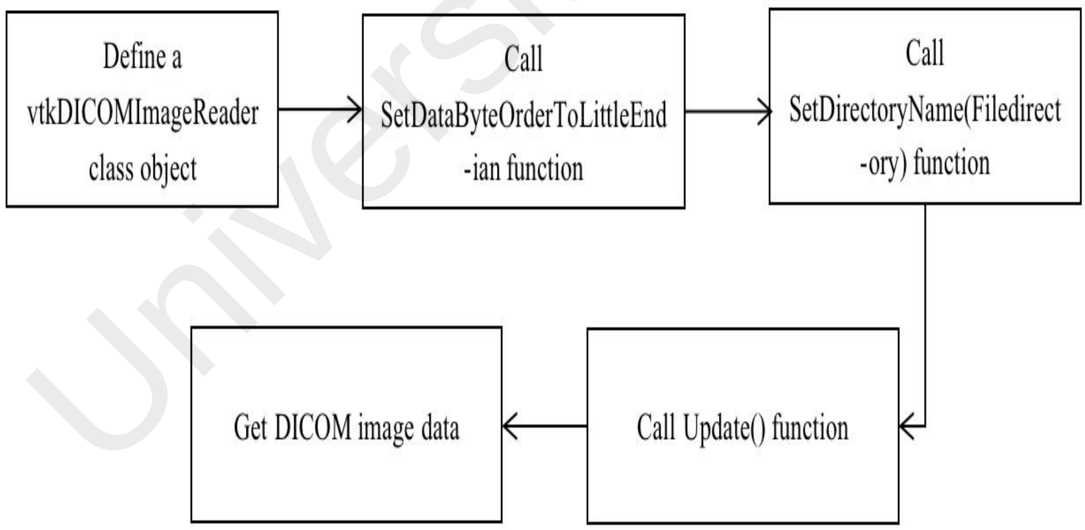


Figure 3. 1 The Flowchart of DICOM Image Data Reading

In Figure 3.1, VTK specifies the file name to be read by instantiating the Reader object, then use call the Update() method to make the pipeline execute and read the corresponding DICOM image file. Similarly, we use vtkJPEGReader to read the JPG image data.

3.3.2 Volumetric rendering process realization

3.3.2.1 3D reconstruction

In VTK, the 3D volume rendering reconstruction process (Figure 3.2) is roughly divided into three steps:

- First, default classification function, assign opacity and color value to each voxel.
- Second, according to the gray value of the voxel at the location of each sampling point and the illumination model, the illumination intensity of the corresponding voxel is calculated.
- Third, calculate the light intensity of the pixel, that is, contribution of all sampling points to screen pixels, then get a 3D image.

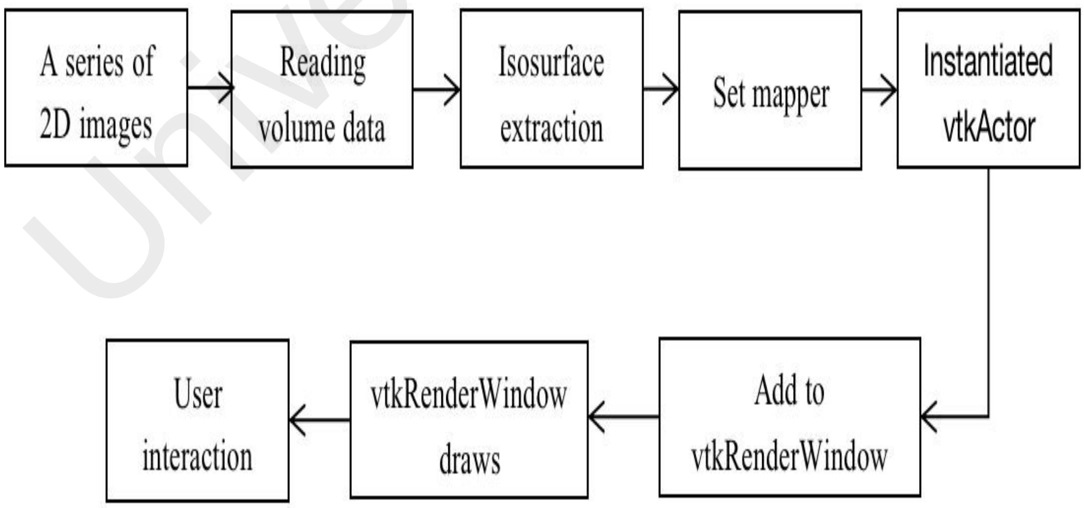


Figure 3. 2 The Flowchart of Volume Render

Actually, VTK provides a common method for 3D volume rendering, namely ray casting. And this algorithm implements 3D reconstruction in two steps (Figure 3.3):

a) Volume rendering data processing: establish the vtkPiecewiseFunction object to set the inflection point of the opacity function and its corresponding opacity after reading CT, MRI, and Ultrasound image data. Build vtkColortransferFunction transfer function to set different colors for different organs or tissues. And establish vtkFixedPointVolumeRatCastMapper to calculate 3D data for ray casting algorithm.

b) Reconstruction of the ray casting method: establish vtkRenderer and vtkRenderWindow respectively, and set vtkRenderWindow as the interactive drawing window, then create a vtkRenderWindowInertactor object.

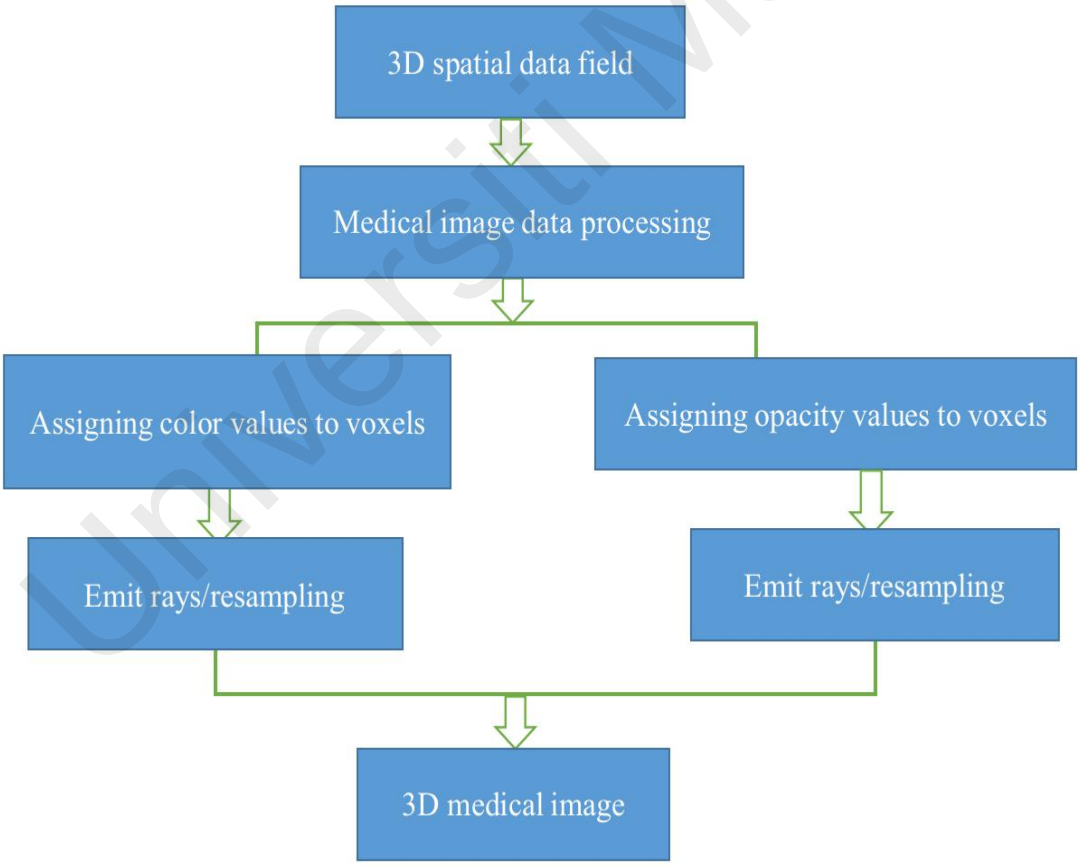


Figure 3. 3 Ray Casting Algorithm Reconstruction Processing

In the process of volume rendering 3D reconstruction, these classes that deserve special attention in the pipeline structure of VTK as shown in the table:

Table 3. 1 The important class in VTK pipeline

vtkRenderWindow	Graphical user interface, including set the size of the rendering window and produce stereoscopic display effects
vtkRender	The base class of Renderer, used to manage Light, Camera, Property, etc.
vtkLight	Control the lights in the scene
vtkCamera	Show the objects in the rendered scene
vtkActor	It is an object rendered by vtkRenderer combined with vtkCamera
vtkProperty	Define the voxel data property, such as opacity, color, and shading
vtkTransform	Used to control the position of each Actor

3.3.2.2 Volumetric rendering

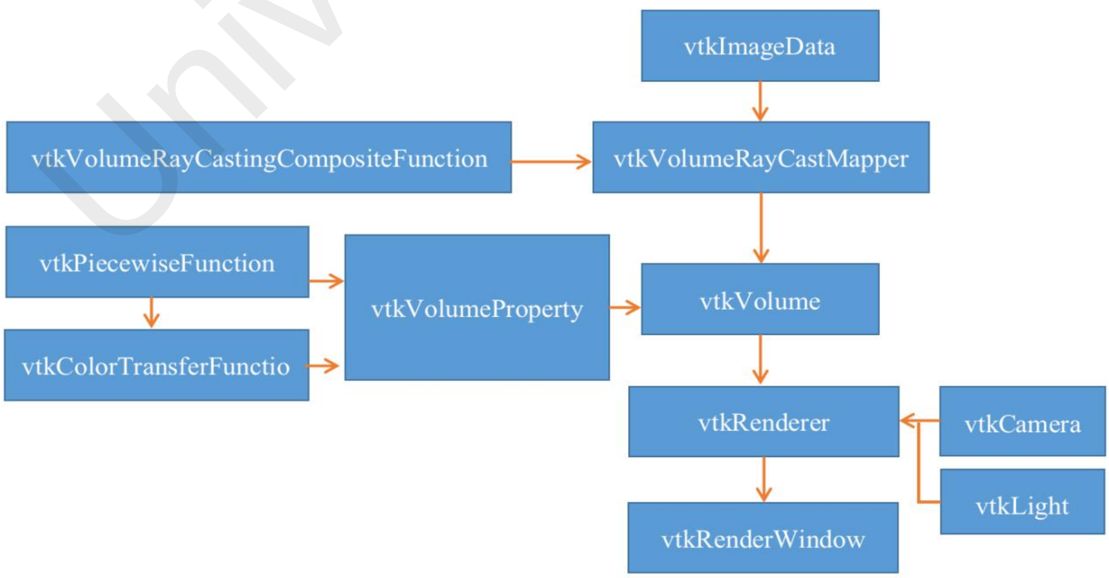


Figure 3. 4 Volumetric Rendering Pipeline

According to the volumetric rendering pipeline, the method and process of volumetric rendering in VTK in this paper are as follows:

a. Read CT DICOM head image file, CT JPG Brain image data, MRI JPG brain image data, and Ultrasound JPG fetal image data respectively. Use the following code, and set the range of resolution and sequence for each medical image type on VTK.

```
V16->SetFilePrefix("C:\\Users\\Danica\\Desktop\\headsq\\heads
q\\quarter");
v16->SetDataExtent(0,1012,0,706,1,25);
v16->SetFilePrefix("C:\\Users\\Danica\\Desktop\\Medical
imaging\\img");
v16->SetDataExtent(0,236,0,236,1,25);
v16->SetFilePrefix("C:\\Users\\Danica\\Desktop\\MRI
brain\\img");
v16->SetDataExtent(0,963,0,768,1,223);
v16->SetFilePrefix("C:\\Users\\Danica\\Desktop\\readyimage\\i
mg");
```

b. Create a mapper, load the volumetric rendering method and medical image data. The volumetric rendering method mainly is ray casting method. Normally, the default sampling length is 1. However, in reality, the smaller the sampling length, the better the rendering effect.

```
vtkVolumeRayCastMapper*volumeMapper=vtkVolumeRayCastMapper::
```

```
New();
   volumeMapper->SetVolumeRayCastFunction(compositeFunction);
   volumeMapper->SetInput(append->GetOutput());
```

c. Extract the actor of the rendering data and set the properties of the actor use SetProperty function. and the tissues and organs in the medical images could be seen as the actor.

```
Volume->SetProperty(volumeProperty);
```

d. Use vtkPiecewiseFunction to define the piecewise function mapping, that is, the Clamping function, and its expression as follows:

$$\text{Clamp}(a, b, x) = \begin{cases} a, & x \leq a \\ x, & a \leq x \geq b \\ b, & x \geq b \end{cases} \quad (3.1)$$

In the above formula, x represents the mapping value of the current gray value (also called parameter), a represents the mapping value of the minimum gray value at the break-point, and b represents the mapping value of the maximum gray value at the break-point. Its function is to limit x between a and b, when x is less than a, in the program, the default mapping value is the corresponding mapping value at the break-point of the minimum gray value, that is, x is equal to a. Vice versa, x is equal to b. in this program, the Clamping function could be use to clamp the gray value into the value we want to achieve so that the rendering effect will become better and intuitively to observe for all of observer whoever professional or non-professionals (patients)

Additionally, the vtkPiecewiseFunction used in this paper sets the opacity value as follows:

```
vtkPiecewiseFunction*opacityTransferFunction=
vtkPiecewiseFunction::New();
opacityTransferFunction->AddPoint(1024+30,0.0);
opacityTransferFunction->AddPoin(1024+255,1);
```

Use vtkColorTransferFunction to map scalar values to color values, and RGB is used as the color space in this paper. Besides, VTK also supports HSV color space, the RGB settings are as follows:

```
vtkSmartPointer<vtkColorTransferFunction>color=vtkSmartPoin
ter<vtkColorTransferFunction>::New();
color->AddRGBPoint(0,0,0,0);
color->AddRGBPoint(64,1.0,0.52,0.3);
color->AddRGBPoint(190.0,1.00,1.00,1.00);
color->AddRGBPoint(220.0,0.20,0.20,0.20);
```

e. Bind the objects in the rendered scene with vtkRenderer through VTKVolume, for example, CT rendering of brain objects in the scene, fetal objects in the ultrasound rendering scene. Finally, add the rendering window (vtkRenderWindow).

Finally, the desired vivid 3D medical rendering model can be obtained. The most important point in this process is that different types of medical images need to present different details, so it is necessary to constantly adjust the appropriate opacity value and color value to determine the best display effect. This is a time-consuming task.

CHAPTER 4: RESULTS AND COMPARISON

4.1 Volmetric rendering results

In this paper, there are three medical images with different imaging principles are selected as rendering objects, and examined the volumetric rendering as the following:

- How well does the volumetric rendering in these medical images?
- Will images of different formats increase the difficulty of rendering?
- Does volumetric rendering make a difference in different medical image?
- Which medical image benefited most with volumetric rendering?
- Is there any factors will affected with volumetric rendering results?

4.1.1 CT head/brain image volumteric rendering

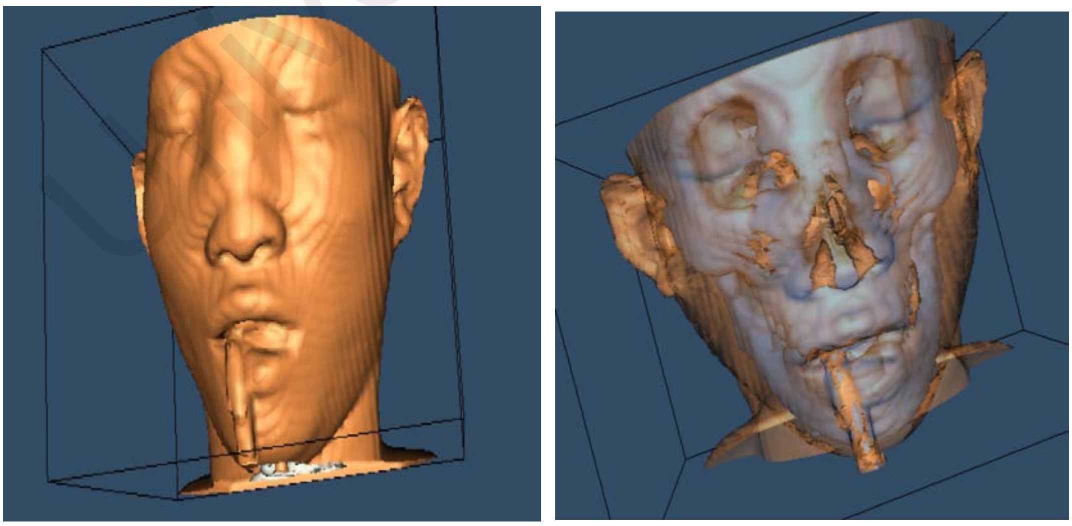


Figure 4. 1 3D reconstruction of CT head image

Extract two isosurfaces representing skin and bones from the read CT volume data set and display them on the render window, set the opacity value to 0.5, as shown on the right side of the figure above, it can clearly see the skin and bones. As Figure 4.1 shown, the more intuitive 3D volume rendering model can be obtained when adjusting the opacity value and setting a contrasting color value.

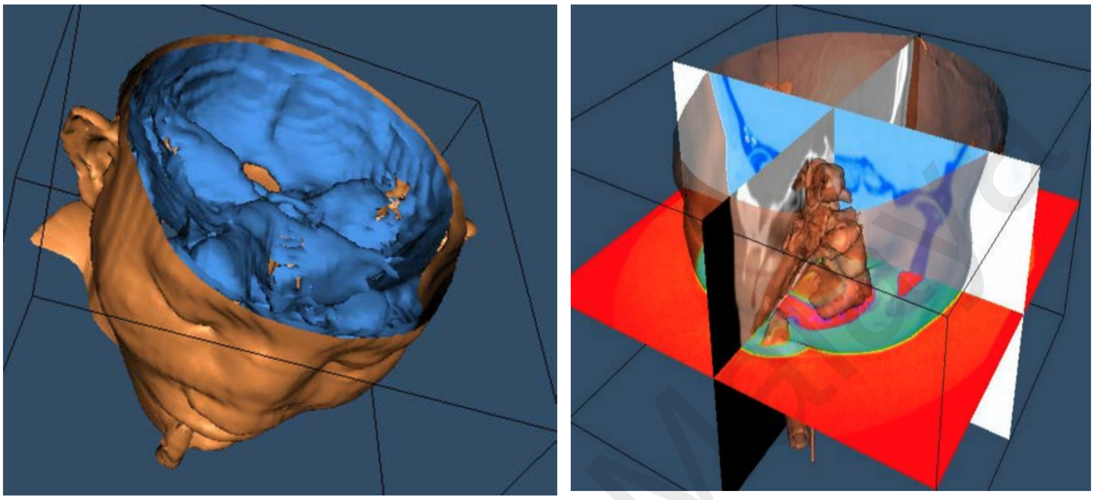


Figure 4. 2 Volumetric Rendering Results of CT Head Image. (89 2D images)

In Figure 4.2 , the picture shown on the left represents the result of volumetric rendering. And in the image on the right, there are three orthogonal planes are created from the sagittal, axial, and coronal directions, rendered in white, black, and red respectively. As the picture above shown, observing the volumetric rendering results from different angles can better observe the internal structure of the brain. This intuitive results has a higher accuracy and intuitiveness than the result of a doctor observing a 2D image. It is of great therapeutic and diagnostic significance and research value. In addition, compared to surface rendering, volumetric rendering can see the spatial details of tissues or organs.

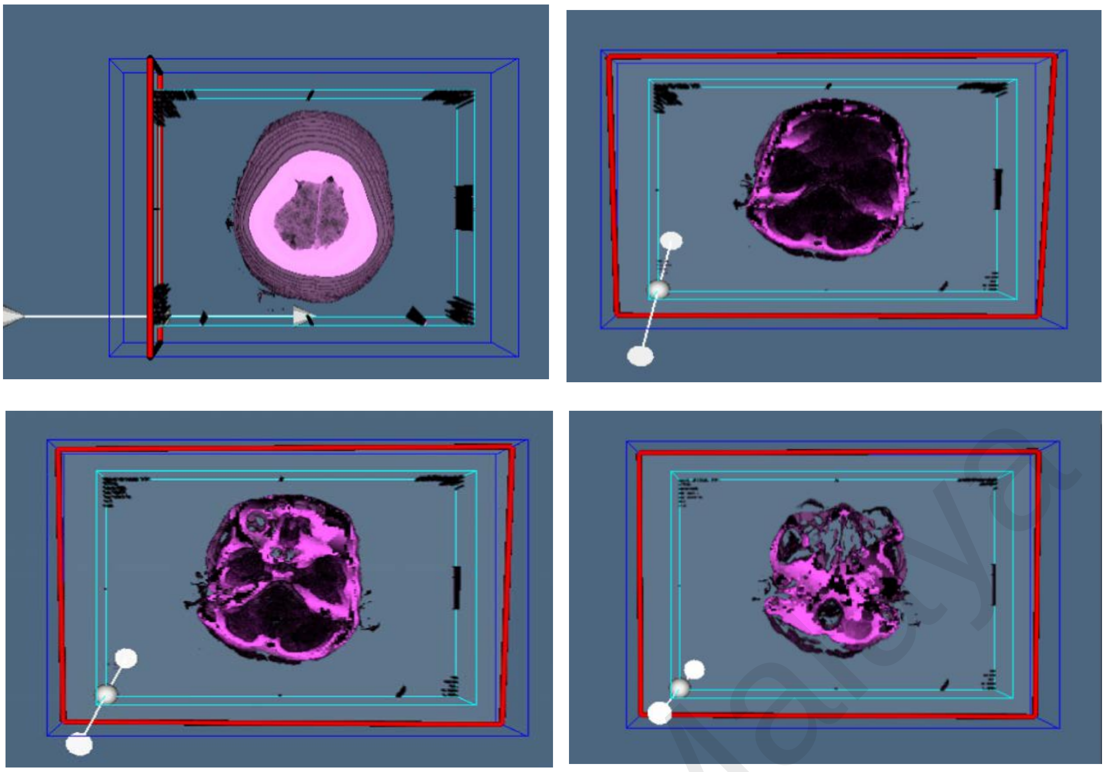


Figure 4. 3 Volumetric Rendering Results of CT Brain Image. (25 2D image with 1012x706)

As shown in Figure 4.3 , By dragging the mouse, we can get rendered images from different angles, which allows us to observe the 3D model of the brain more intuitive. It is not difficult to see from the pictures that the rendering results are not ideal, the possible reasons are as follows: (a). Failed to set opacity value, the opacity value is not used to distinguish different tissues and organs. (b). Failed to set color value, the color contrast is not well used to distinguish tissues and organs clearly. (c). The quality of the acquired 2D image is not good, resulting in poor reconstruction effect. (d). Maybe the volumetric rendering is not suitable for 3D volumetric rendering of this medical image.

4.1.2 Ultrasound fetal image volumetric rendering

In this study, the 2D B-mode ultrasound image collected from the fetal phantom is used for reconstruction and rendering. First, use 100 and 200 other 2D fetal image with a resolution of 320x240 to reconstruction respectively, as shown in Figure 4.4.

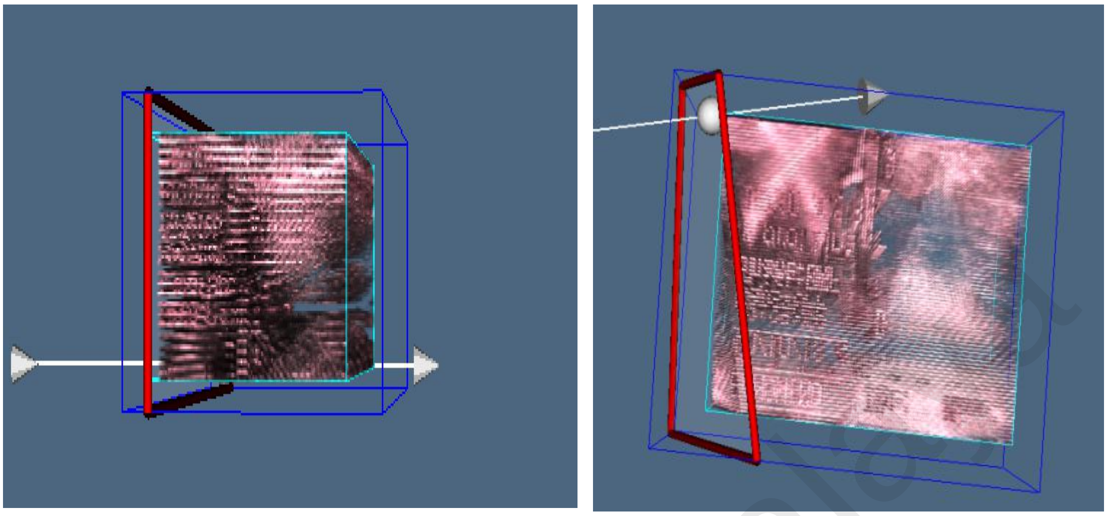


Figure 4. 4 The Fetal Image. The picture on the left is the reconstruction result of 100 2D images, the right is the reconstruction result of 200 2D images. the reconstruction effect is very bad, and can't see the shape of the fetus from any angle

Next, after fetal phantom image reconstruction, in addition to image pre-processing, here also made some adjustments to the opacity value, adjust the original AddPoint(1024+80, 0.0) to AddPoint (1024+30, 0.0) through the opacityTransferFunction, the 1024 express the pixel value, the 80 and 30 represent the expected opacity value. In fact, it can be found that the opacity value lower than 30 will make the fetal phantom image smoother after multiple tests and comparisons (*Figure 4.4*).

It can be found that the same problem as in Figure 4.3 has occurred, and the volumetric rendering effect also is not good. The possible reasons for this rendering result, in addition to the explanation in Figure 4.3, may mainly be the problem of the algorithm and the image itself.

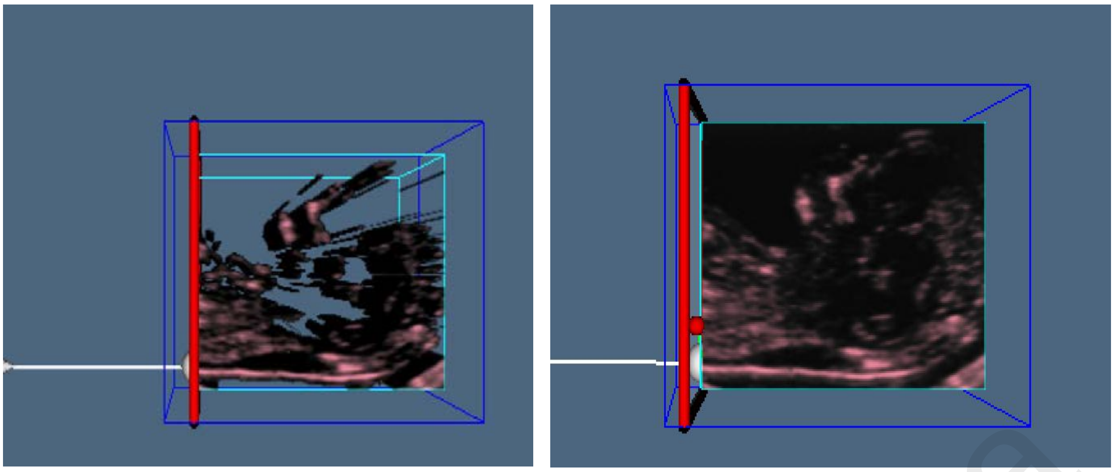


Figure 4. 5 The parameters on the left are SetDataSpacing=(1,1,10), Opacity Value=80; And the right are SetDataSpacing=(1,1,10), Opacity Value=30

Sometimes the opacity value is not as big as better, this point can be confirmed in Figure 4.5, on the left, it's difficult to see what it is, if don't know which image the model is reconstructed from in advance. Although the reconstruction effect on the right is also not good, almost restored the 2D image.

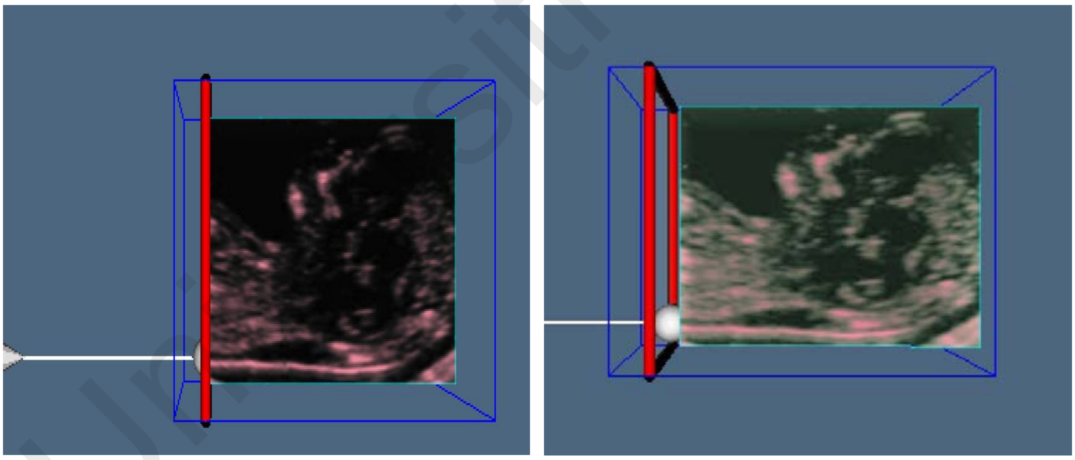


Figure 4. 6 The result of adjusting the color value. On the left, set the color value of the fetal phantom image: AddRGBPoint=(0, 0, 0). On the right, set the color value of the fetal phantom image: AddRGBPoint=(0.3, 0.6, 0.4)

On the basis of Figure 4.5, adjust the color value to enhance the contrast, it seems easier to recognize Ultrasound fetal phantom image from the right model, but the effect is still not good, so after trying the color value adjustment effect many times, this research decided to try to adjust the light parameters, as Figure 4.7 shown.

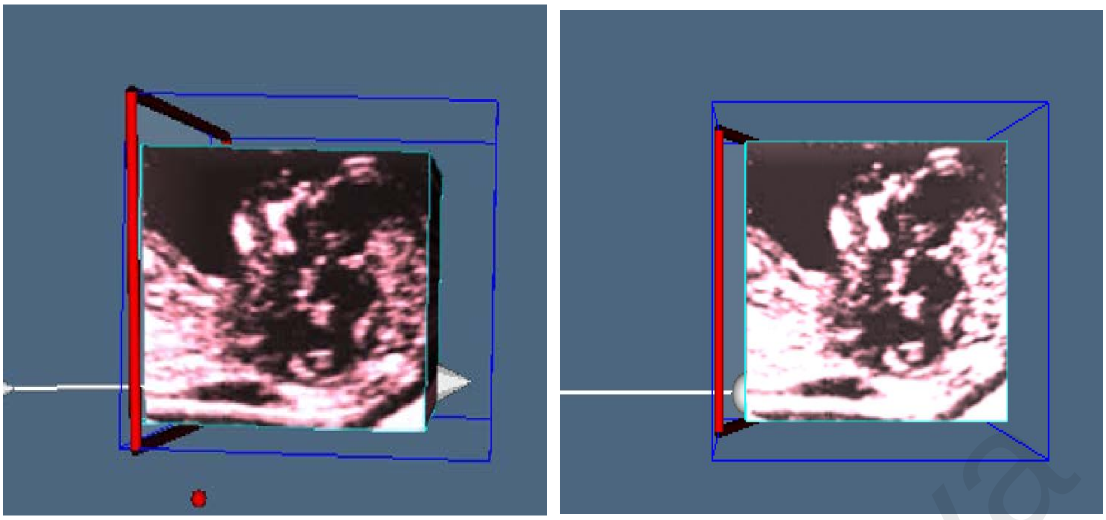


Figure 4. 7 The vtkVolumeProperty adjustment. There are three parameters have been adjusted, the left shown the SetAmbient=4, SetDiffuse=4, SetSpecular=0.4. The right shown SetAmbient=6, SetDiffuse=6, SetSpecular=0.6

Both SetAmbient() and SetDiffuse() are used to determine the lighting properties, The SetAmbient() set the ambient light coefficient, the SetDiffuse() set scattered light coefficient. In the same time, it will affect the volumetric rendering effect when the value of SetAmbient() and SetDiffuse() increases from small. The SetSpecular() set the reflected light coefficient, and the render window will become brighter and brighter as the value of SetSpecular() increases, then the most intuitive result is the loss of a lot of details (*Figure 4.7*).

4.1.3 MRI brain image volumetric rendering

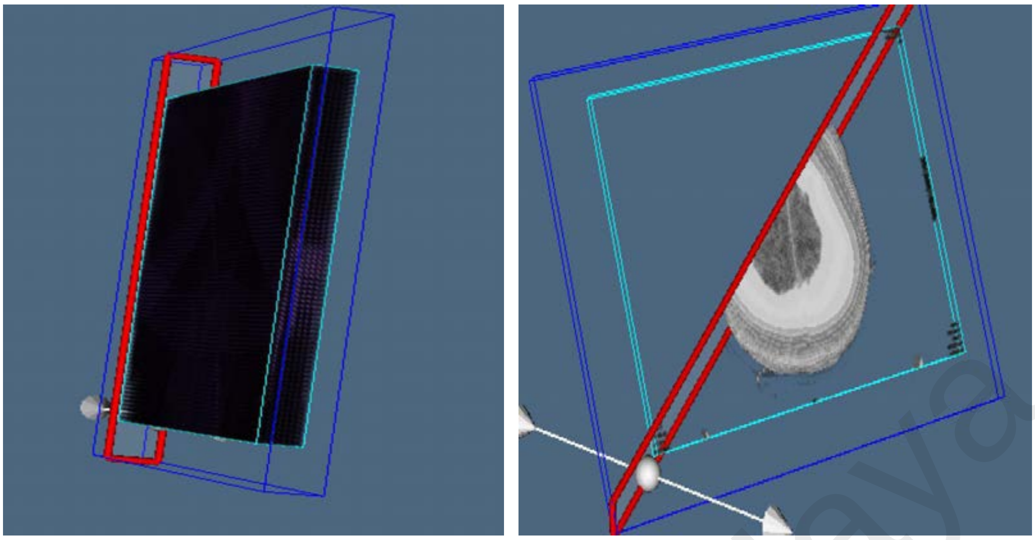


Figure 4. 8 MRI brain volumetric rendering image (236x236)

In Figure 4.8, Viewed from the side (left), the effect of the MRI 3D image is very poor, and totally can't see what it is. After adjusting the light coefficient, opacity and color value, the MRI brain image can be seen clearly (right).

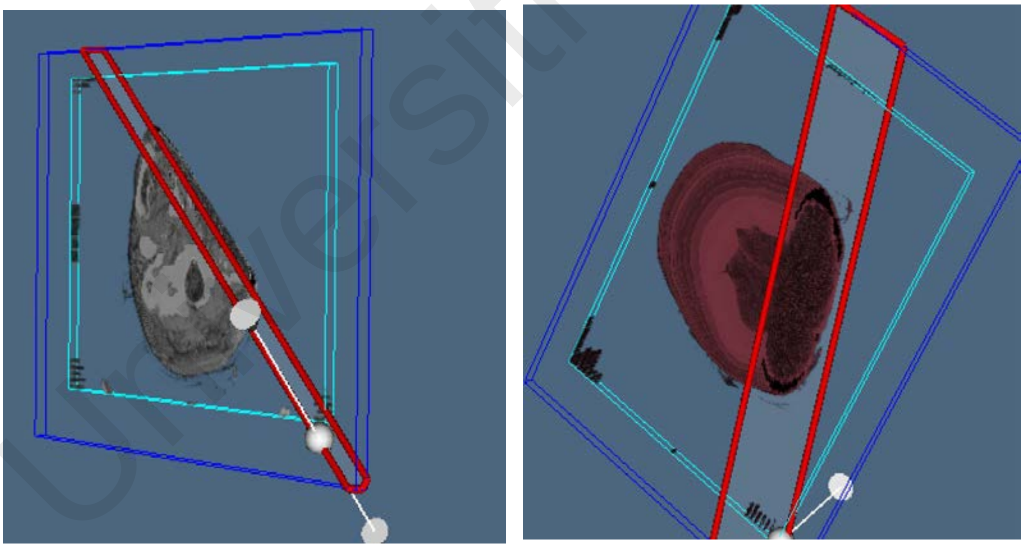
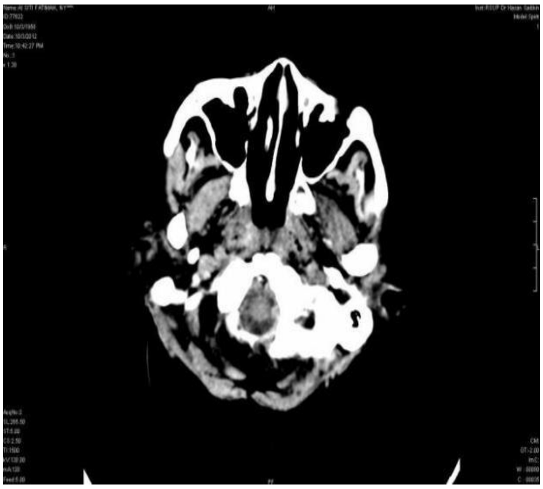
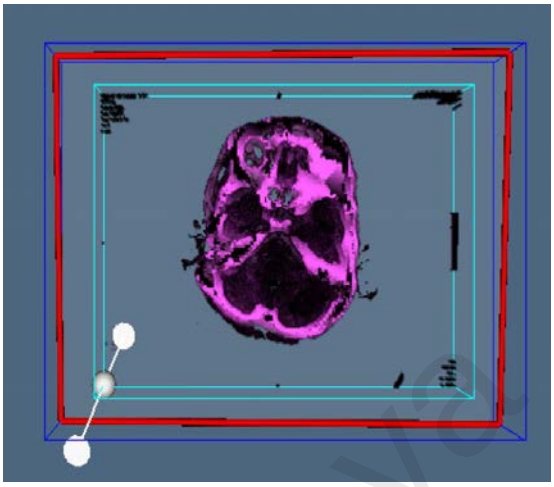


Figure 4. 9 MRI brain volumetric rendering images from different angles

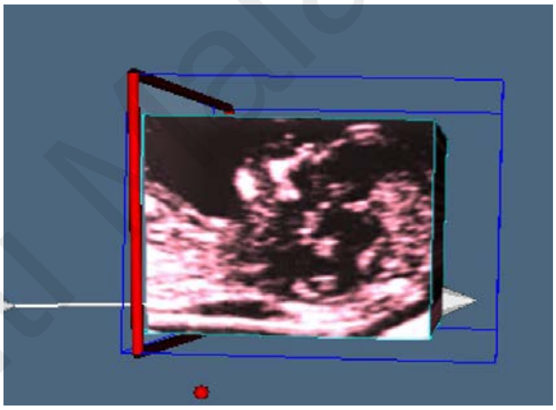
In Figure 4.9. Observing from different angles, it can be found that the number of 2D slices is relatively too small, resulting in a rough image after 3D construction and volumetric rendering.

4.2 CT vs ultrasound vs MRI

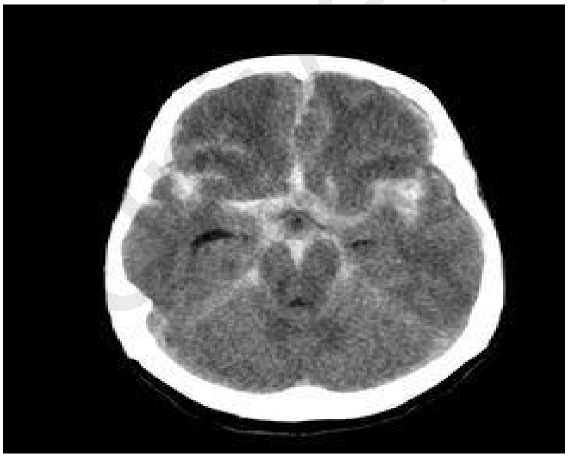


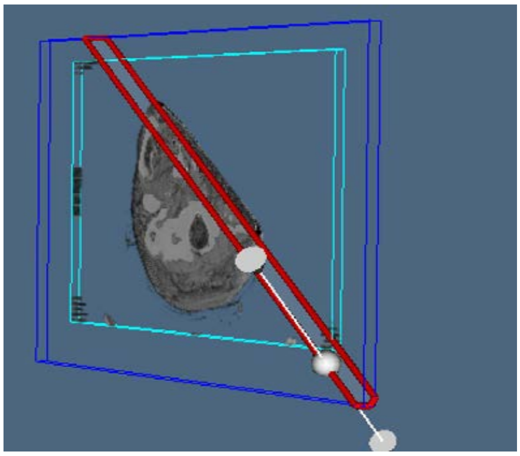


(a) 2D CT brain slice **(b) Volumetric rendering**



(c) 2D ultrasound image **(d) Volumetric rendering**





(e) 2D MRI brain slice **(f) Volumetric rendering**

Figure 4. 10 Compare three medical images (include 2D and 3D)

First of all, for convenience, this paper chooses CT brain images for comparison, as shown in Figure 4.10 (a) and (b). Second, by comparing the 2D and corresponding volumetric rendering image, the volumetric rendering image in VTK can distinguish skin from bone by set different opacity value, which is more convenient for observation (professional and amateur). Third, from the number of 2D slices/images used, although both CT and MRI are use a smaller number of slices, the results obtained are different, the specific reasons will be discussed in chapter 5.

4.3 Key findings

Based on the above, there are several key findings from this paper of volumetric rendering:

- ✓ Volumetric rendering speed is directly related to the number/size of medical image/image data: the computer can give the results almost instantly when the volumetric rendering of CT and MRI brain images with only 25. However, when running 2D ultrasound images with more than two hundred images, the speed of volumetric rendering slows down significantly.
- ✓ The realism of volumetric rendering images is directly related to the number of 2D slices/images: the more 2D slices, the more details the image contains, then the better the rendered effect after 3D reconstruction. I will discuss this one with practical examples in the next chapter.
- ✓ The results of volumetric rendering are largely affected by the quality of 2D slices/images: according to the comparison between the 2D image of the fetal phantom and the 2D slices of the CT brain in the previous section, almost all the details in the 2D CT brain slice can be found in the volumetric rendering image, but no matter how adjust the value of the rendering color or opacity of the ultrasound fetal phantom image, it is difficult to obtain a higher quality image.

CHAPTER 5: DISCUSSION

5.1 About the past development

In the eighties of the twentieth century, under the exploration of 3D CT and MRI images, 3D volumetric rendering was becoming medical field significant. The most typical example is the medical tycoons have successively invested in volumetric rendering including Siemens and GE Healthcare, in addition, apply volumetric rendering technology to improve medical standards (Johnson & Hansen, 2011).

In 2005, Bruckner *et al.* (2005) proposed the context-preserving volume rendering method, which provide a simple interference and intuitive meaning for examining the interior of volumetric data set but no need to do any pre-processing. Got to say, the volumetric rendering method extended from the direct volume rendering and the gradient-magnitude opacity-modulation does achieve good results to some extent (*Figure 5.1*).

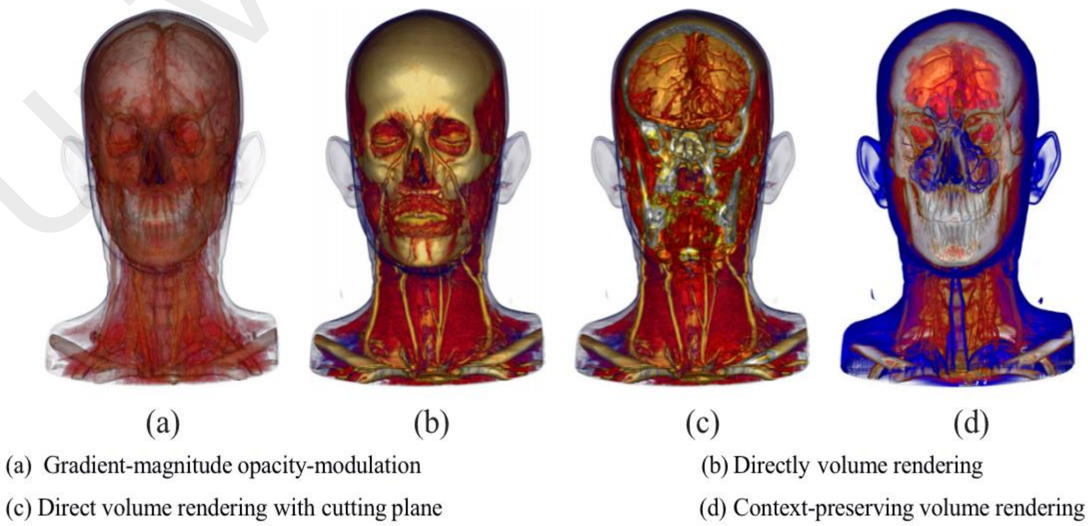


Figure 5. 1 CT angiography data set with different volume techniques

Note: source by Eurographics: VGTC Symposium on Visualization (IEEE). (2005)

In 2008, an article on 3D direct volume rendering published by Callahan et al.(2008) also mentioned that it promotes the development of volume rendering in medical image application because of the huge demand for 3D medical data in medical field.

Due to its comprehensive functions, VTK has always had its unique advantages in 3D volumetric rendering, Unfortunately, because its pipeline has not kept up with the technological upgrading to some extent. Hence, Yang and his partner (Yang *et al.*, 2013) adopt a GPU accelerated method based on VTK to obtain the ideal 3D image. It has successfully applied to ordinary ultrasound equipment to realize 3D volumetric rendering of the liver that can be used for medical diagnosis.

Judging from the results of research by many scholars or researchers and volumetric rendering algorithm in the past, the voxel-based volume rendering algorithm is still unable to meet the needs of current medical treatment and diagnosis at this stage. Thus, considerable research and development are still needed.

5.2 About current development

Numerous studies have shown that volumetric rendering overcomes shortcomings of surface rendering and shows impressive results (Fishman *et al.*, 1987). In this paper, when rendering medical images, surface rendering and volume rendering are firstly carried out by using DICOM data file of CT head. As shown in Figure 4.1 in Chapter 4, after the surface is rendered, only the outline of the head image can be seen. The color is brilliant, but the image quality in actual medical diagnosis is not obvious than some 2D slices. On the contrary, after traversing the volume data of all input images, different opacity values, illumination coefficient values, and the color values are set for voxels with different gray values to display the light and shade. So the surface skin and bone shape can be clearly seen from the picture.

Although the ray casting method is currently the most widely used volumetric rendering algorithm, it obviously cannot meet the needs of massive medical images. Many improved algorithms based on this algorithm have emerged one after another. Therefore, volumetric rendering is an inevitable development trend in medical image applications, and improved ray casting algorithms are a long-term development trend in medical applications.

5.3 About future development

In fact, it can be find that the development of 3D volumetric rendering in medical image applications cannot be separated from these two words: efficiency and quality. There are several merit worthy to recognize in development:

- ❖ The complicated process of viewing massive medical images by professionals and the uncertainty of diagnosis are omitted, and the accuracy and efficiency of medical diagnosis are improved.
- ❖ The 3D volume rendering image can observe the detailed information of the lesion from different angles, which improves the quality of medical images

and reduces the difficulty of communication between doctors and patients.

- ❖ Performing 3D volumetric rendering of the surgical site before the operation is helpful for the revision of the surgical plan, reduces the risk of the operation, and increases the success rate of the operation.

However, the controversial is that there are a lot of 3D reconstruction software and 3D volumetric rendering algorithms. In theory, these software and algorithms seem to meet the needs of current applications, nevertheless, there are no any technologies and algorithms that can be used widely in clinical practice or be recognized by the public, In particular, the various functions even reduce the quality of medical images, resulting a series of problems such as loss of detail and position calibration errors in the rendered image.

All in all, in the future development process, it is recommended to start from the image quality and try to propose a 3D volume rendering technology that can be used as a unified standard (or gold standard). the existing algorithm can be improved on the basis of predecessors, or combine different types of algorithms for use. In addition, it can try to improve its rendering pipeline process to improve rendering speed and efficiency based on the 3D volumetric rendering of VTK.

CHAPTER 6: CONCLUSION

This paper centered on the application of 3D volumetric rendering technology in medical images, and make a detailed analysis of the development of 3D volumetric rendering in medical image application. This paper covers the following tasks are summarized as follows:

Firstly, from the imaging principle, give the analyze and discuss of 2D CT, MRI, and ultrasound images in the early stage. Introduced its advantages and disadvantages respectively. Elaborate the importance of 3D reconstruction in medical images application from the side.

Secondly, this paper just briefly introduces the DICOM format, which is one of medical image standard formats due to this paper mainly uses .jpg format medical images,

Thirdly, this paper gives a detailed introduction to VTK. In particular, the application of VTK-based 3D volumetric rendering in medical images has been focused on this study and discussion. The C++ codes and results display of 3D volumetric rendering of CT head & brain images, MRI brain images and ultrasound fetal phantom images are completed on the visual studio 2008 platform. On the basis of 3D volumetric rendering results, summarized and analyze the advantages and disadvantages of 3D volume rendering technology in medical images from the positive side.

In the end, this paper discusses the development of 3D reconstruction volumetric rendering methods in medical image applications in detail from these three aspects:

past, present, and future.

Furthermore, this study has two limitations, The first is this paper mainly studies the application of VTK based ray casting algorithm in CT, MRI, and ultrasound images. There is a lack of consistency when selecting 2D medical image data, it did not choose the different image data with the same number and resolution, which may caused errors in the research results. And other is due to the limitation of the research environment, the amount of 3D reconstructed image data is generally small and lacks a certain degree of objectivity.

Due to the complexity of the medical image itself, large amount of medical image data, the limitations of the operating platform and the VTK toolkit in achieving 3D volumetric rendering, this research project still needs further research. Throughout this article, i made the following suggestions for future research directions:

1) Although the current 3D volumetric rendering effect can meet the basic clinical treatment and diagnosis, there are still many limitations that make it unable to be widely used in clinical applications. Thus, delve into 3D volumetric rendering, to further optimize the algorithm program so that it can improve the image quality as much as possible while increasing the speed of 3D volumetric rendering is a problem that must be further studied.

2) Well-known, to obtain a high quality and more realistic 3D volumetric rendering model, a large amount of medical image data is needed to construct the details, but it will over burden on operating system, especially, for PC. Therefore, it is necessary to propose a lossless image quality compression algorithm.

3) There is evidence that the fusion of different forms of medical images to form a new multimodal image will become a major breakthrough in the development of medical images. It is worth to be one of the research directions,

In conclusion, due to my limited knowledge and skills, there may be some omissions or deficiencies, please criticize and correct me.

CHAPTER 7: REFERENCES

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