Application of Medical Image 3D Visualization Web Platform in Auxiliary Diagnosis and Preoperative Planning

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***Abstract*—Three-dimensional visualization of medical image data can enable doctors to observe images from more angles and higher dimensions. It is of great significance for doctors to assist in diagnosis and preoperative planning. Most 3D visualization systems are based on desktop applications, which are too dependent on hardware and operating system. This makes it difficult to use across platforms and maintain. Web-based systems tend to have limited capabilities. To this end, we developed a web application, which not only provides DICOM (Digital Imaging and Communications in Medicine) image browsing and annotation functions, but also provides three-dimensional post-processing functions of multiplanar reconstruction, volume rendering, lung parenchyma segmentation and brain MRI (Magnetic Resonance Imaging) analysis. In order to improve the rendering speed, we use the Marching Cube algorithm for 3D reconstruction in the background in an asynchronous way, and save the reconstructed model as glTF (GL Transmission Format). At the same time, Draco compression algorithm is used to optimize the glTF model to achieve more efficient rendering. After performance evaluation, the system reconstructed a CT (Computed Tomography) series of 242 slices and the optimized model was only 6.37mb with a rendering time of less than 2.5s. Three-dimensional visualization of the lung parenchyma clearly shows the volume, location, and shape of pulmonary nodules. The segmentation and reconstruction of different brain tissues can reveal the spatial three-dimensional structure and adjacent relationship of glioma in the brain, which has great application value in auxiliary diagnosis and preoperative planning.**

***Keywords*—3D visualization, auxiliary diagnosis, preoperative planning, web application**

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I. INTRODUCTION

Three dimensional visualization of medical images can better show the true stereoscopic anatomical conformation. Doctors can make preoperative planning and risk assessment by stereoscopic observation of the focus and its peripheral nerves, blood vessels and other tissues [1]. It is very suitable for departments that need fine surgery, such as neurosurgery, cardiovascular surgery, etc. A good preoperative planning can eliminate the focus to the greatest extent, and at the same time, minimize the damage to other tissues, reduce the surgical risk and improve the prognosis. In the past two decades, some excellent 3D visualization software of medical images has been developed. For example, 3dslicer [2, 3], MITK (The Medical Imaging Interaction Toolkit) [4, 5], etc. are medical image processing and analysis application platforms, which have powerful image analysis, reconstruction, visualization functions, and a large number of extensions. They are widely used in medical research, auxiliary diagnosis, and preoperative planning. But most of them are desktop based applications. Desktop-based applications often rely on a specific operating system, it is difficult to access our applications on different devices. At the same time, when installed inside the hospital, remote access and data sharing is difficult. In addition, it takes a lot of time and technical support to complete the installation and maintenance of the system. There are also some Web software developed, such as OHIF (Open Health Imaging Foundation) [6], DWV (DICOM Web Viewer) [7], etc., but most of them lack 3D visualization function, and the application scene is relatively simple. With the development of WebGL (Web Graphics Library, a 3D

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Graphics protocol) technology, it is possible to realize 3D visualization through web platform. Cloud computing [8] provides us with rich, high-performance configurable resources and a good platform for our Web applications. Under the background of telemedicine [9], the application based on Web can achieve free installation, real-time data sharing and remote diagnosis. Therefore, It is necessary to develop a professional, functional, extensible and user-friendly Medical Image 3D Visualization Web Platform.

In this study, we have designed and developed a new 3D visualization platform for medical image. The main contributions are as follows:

- We adopted asynchronous reconstruction in the background, persisted the 3D model into glTF (GL Transmission Format), and optimized the 3D model with Draco compression, which greatly improved the rendering speed.
- Lung CT (Computed Tomography) analysis module was developed. The reconstruction and segmentation of pulmonary parenchyma is of great significance in the auxiliary diagnosis of pulmonary nodules.
- The brain MRI (Magnetic Resonance Imaging) analysis module was developed to help doctors with preoperative planning through skull separation, brain tissue segmentation, and reconstruction of different brain tissues.

II. SOFTWARE DESIGN AND IMPLEMENTATION

A. Software Architecture

The system is designed based on the distributed web architecture by adopting the idea of separating the front end and the back end. Fig. 1 shows the structural block diagram of the system. According to the division of business logic, the system is composed of a front-end server and three back-end servers, including web server, image processing server and image segmentation server. At the same time, an nginx [10] server is added to be responsible for reverse proxy request forwarding and load balancing. Adopting such an architecture greatly reduces the coupling between business modules, thus increasing the stability of the system. It also provides scalability for our subsequent development of business modules. Configuring a reverse proxy server protects the service server and ensures resource security. In addition, load balancing reduces the load on service servers and improves performance. The front-end server integrates Cornerstone Series Library [11], Papaya JS Library [12], and Playcanvas 3D Engine [13], which is mainly used for user interaction, image and 3D model rendering. Among background servers, the Web server is responsible for the interaction with the front end, such as the return of case list and the combination query of cases.Image processing server is used for image path analysis, 3D reconstruction, 3D model optimization and other functions. Segmentation server is responsible for image data preprocessing, such as lung parenchyma segmentation, skull stripping and segmentation of brain MRI images, etc. Finally, it communicates with the image processing server and sends the preprocessed data into the reconstruction algorithm for 3D reconstruction. In addition, the image storage server provides persistent storage for clinical image data.

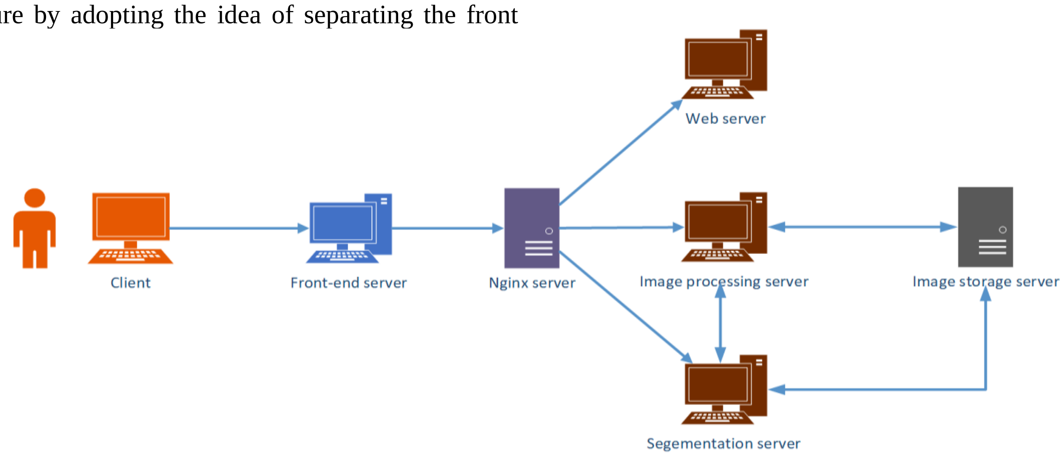


Figure 1. Software architecture diagram. It shows the distributed design architecture of software and the communication relationship between each server.

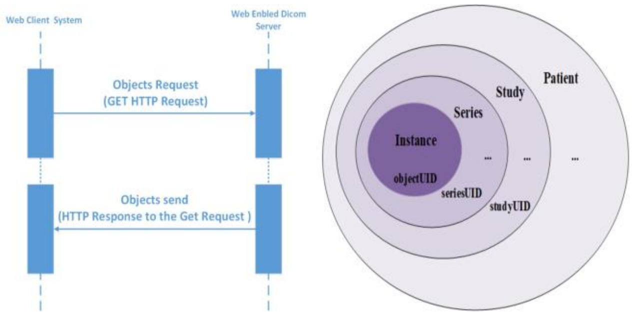
B. DICOM Image Parsing and Display

The software was developed with cornerstone family of libraries. Cornerstone is a lightweight Web-based javascript library that enables the display and interaction of medical images in modern Web browsers. Cornerstone supports DICOM (Digital Imaging and Communications in Medicine) image parsing and interaction with the WADO (Web Access to DICOM Persistent Objects) [14] interface for image retrieval. Cornerstone has excellent performance. It not only supports CPU (Central Processing Unit) and GPU (Graphics Processing Unit) to render medical image sequences, but also uses multi-threaded coding to accelerate image display. Because of its good scalability, it can be easily integrated with our system. In addition, it also provides us with the cornerstoneTools component to help annotate and measure medical images.

We developed a RESTful [15] image path parsing interface that follows Web Access to DICOM Persistent Objects (WADO) protocol. It is defined by the DICOM 3.0 standard for clients to be able to retrieve images from a Web Enabled DICOM server (DICOM server that supports web communication mechanism) with a common HTTP (Hyper Text Transfer Protocol) request. Its communication model is shown in Fig. 2a. WADO protocol is used to generalize the format of URL (Uniform Resource Locator) for accessing DICOM server, so as to make clients and DICOM server of different manufacturers compatible with each other and obtain images. It is essentially an HTTP GET Request that retrieves different images by setting different parameters. Specific parameters are shown in Table I. WADO Request uses a three-tier architecture to retrieve images: Study, Series, instance. A Patient can be studied multiple times. Each study contains one or more sequences of medical images, called Series. The image in the series is divided into multiple files for storage, called Instance. An instance is a DICOM file containing a single image. The retrieval logic is shown in Fig. 2b.

TABLE I. WADO REQUEST PARAMETER TABLE

Parameters	Meaning	Parameters	Meaning
studyUID	Unique identifier of the Study	annotation	Annotation on the object
seriesUID	Unique identifier of the Series	windowCenter	Window center of the image
objectUID	Unique identifier of the Object	windowWidth	Window width of the image
requestType	Request type	imageQuality	Image Quality
contentType	MIME type of response	transferSyntax	Transfer Syntax UID
Charset	Charset of the response	rows	Number of pixel rows
Anonymize	Anonymize object	columns	Number of pixel columns



(a) (b)

Figure 2. (a) is the WADO communication model. (b) is the logical structure of image retrieval by WADO Request.

C. Lung CT and Brain MRI Data Analysis

In order to carry out 3D reconstruction of the lung, we need to extract the lung structure from the CT image. Here, traditional image processing methods are used to extract the lung. First of all, we adjust the window width of the image to 1000 and the window level to −350 (the experiment has a good effect), and then use threshold segmentation [16] method for binarization processing of the image. Since the lungs themselves are the two large cavities in the chest cavity, the CT value of the air is −300, so we set the CT value greater than −300 to 1, and the CT value less than −300 to 0. The seed filling algorithm is used to segment the inner trunk from the outer air, and then the initial mask is obtained by subtracting the trunk from the threshold image. The lungs are inflated by morphological closure, the small holes caused by lung fibers are filled, and then corrode and restore to their original size. Finally, the maximum connected domain is reserved to obtain the final mask. Mask was fused with the original image to obtain the segmented lung image, which was fed into our reconstruction algorithm for reconstruction. The renderings of the whole process of lung CT segmentation and reconstruction are shown in Fig. 3.

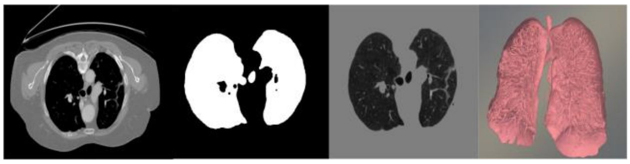


Figure 3. Represents the whole process of pulmonary segmentation and reconstruction. From left to right are original lung CT, segmentation mask, segmented image after fusion, and reconstructed model.

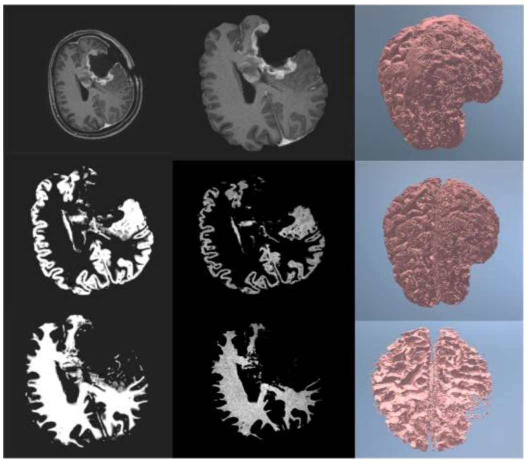


Figure 4. Represents the whole process of MRI analysis of a patient with glioma. From left to right, the first row is: original MRI image, MRI image after skull stripping, whole brain reconstruction model; The second row is: gray matter segmentation mask, gray matter segmentation image, gray matter reconstruction model; The third row is: white matter segmentation mask, white matter segmentation image, white matter reconstruction model.

The reconstruction of brain parenchyma is similar to that of lung parenchyma, in that tissue must be extracted first. For MRI images of the brain, we need to strip the skull and then segment it. Brain tissue is divided into three parts: cerebrospinal fluid, gray matter, and white matter. Here we only segment gray matter and white matter images. FSL (FMRIB Software Library, FMRIB is Functional MRI of the Brain) [17, 18] is an open source tool library for MRI brain imaging data analysis. The BET function of FSL can be used to extract brain tissue, and the FAST function of FSL can be used to segment brain tissue. The underlying method is based on hidden Markov random field model and associated expectation maximization algorithm. We integrate it into our system and use command calls. As shown in Fig. 4, This is an MRI image of a patient with a glioma. We use the FSL-

BET module to strip the skull first, and then fed the stripped image into the reconstruction algorithm to obtain the whole brain 3D model. Then the images after skull stripping were sent into the FSL-FAST module for segmentation, and gray matter mask and white matter mask were obtained. Then, the mask and the original image are fused to obtain the segmented images, which are respectively fed into the reconstruction algorithm to obtain the 3D models of gray matter and white matter.

D. Reconstruction and Optimization of 3D Model

At present, most systems use real-time reconstruction, which will cause a long time delay for users. When we repeatedly review the model, it needs to be reprocessed, which causes a waste of time and resources. To do this, we use asynchronous reconstruction and save and optimize the model for more efficient rendering. We use multithreading to perform multiple subtasks from image processing to reconstruction and return messages to the interface in an asynchronous manner. Users can get feedback when they start rebuilding a task, and the progress is displayed in the form of a progress bar. This allows users to feel only the model rendering time and not the image processing, reconstruction, etc. in the background. In addition, the model can be directly loaded and rendered in the second rendering, without image processing, reconstruction and other operations. Firstly, the Marching Cube algorithm [19] encapsulated by VTK (Visualization Toolkit) [20] is used for 3D reconstruction, and the reconstruction results are saved as OBJ model, and the OBJ model is converted into glTF model by obj2gltf command script. glTF [21] model is the most suitable 3D model format for Web applications at present. It provides a solution for efficient transmission and rendering of 3D models on the Web. glTF is designed according to the data format of the graphical interface, which allows it to be loaded directly by graphics cards and WebGL, and its binary storage form makes it the most efficient transfer. A complete glTF data usually contains three parts as shown in Fig. 5a: one is a Bin file, which stores vertex coordinates, vertex normal coordinates, image texture information and so on in the form of binary stream; The other is the JSON (JavaScript Object Notation) file (.gltf), which is the index of the model vertex, basic data, material and other information in the binary file; The third is some images for textures. The structure of the JSON file is shown in Fig. 5b. Scene object is the entry point of the file, node is the root node of the scene, mesh describes the grid data of 3D objects in the scene, it accesses the real geometric data by referring to the accessor object, and the material object it references defines the appearance of 3D objects.

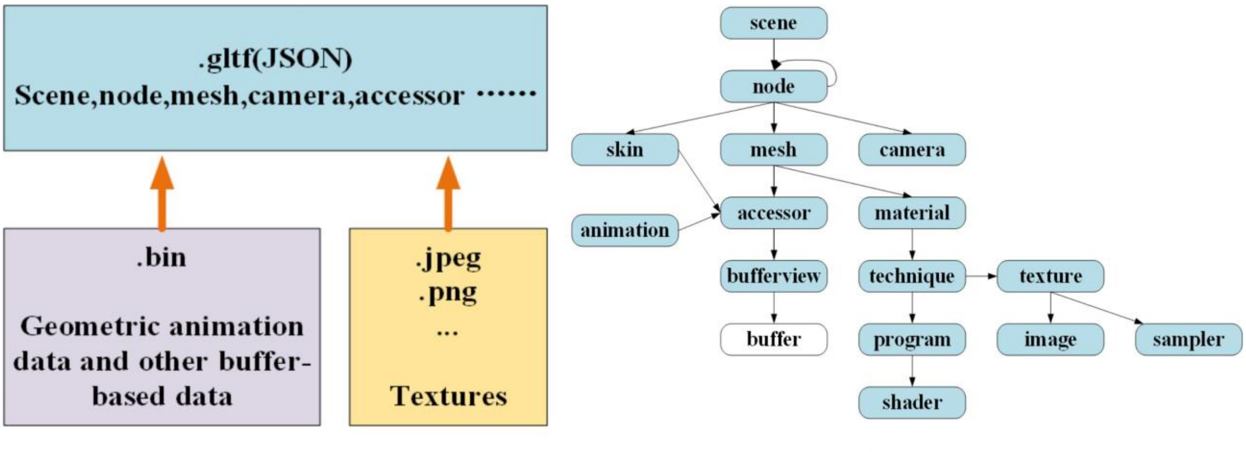


Figure 5. (a) is the structure contained in a complete glTF data. (b) is the organizational structure of the JSON file.

In order to further optimize the model structure, Draco [22] is used to compress the glTF model. Draco is a library of 3D model compression and decompression tools developed by Google. Draco reduces the number of bits of information such as vertex coordinates, vertex texture coordinates, and data storage. Meanwhile, it changes the index method of grid data of the model, making the model more lightweight while ensuring the visual effect of the model. The overall optimization process includes using VTK's Marching Cube algorithm to reconstruct DICOM image and save it as obj model, converting obj model to glTF model through obj2gltf command script, and finally using gltf-pipeline command script for Draco compression to obtain the final model. The process is shown in Fig. 6.

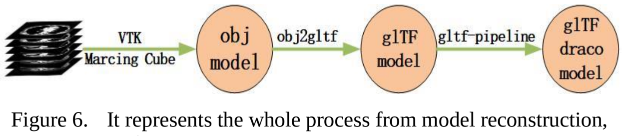


Figure 6. It represents the whole process from model reconstruction, format conversion to model compression.

III. Result

A. Software Features

The medical image 3D visualization Web platform supports the entire workflow from docking with PACS (Picture Archiving and Communication System) system for DICOM instance acquisition, to image display and 3D analysis. Its specific features include:

- Connect with PACS server to obtain DICOM images.
- Load the DICOM images from the specified file or directory.
- Query and retrieve images according to patient name, date and other parameters.
- The ability to display images, load image information, and support multi-series, multi-image display.
- Use standard tools to manipulate images including: adjust window width and window level, zoom, flip, pan/move, negative image, pseudo color, and auto play.
- Ability to annotate and measure images using standardized tools including: length measurement, Angle measurement, cardiothoracic ratio measurement, rectangular annotation, manual segmentation annotation, and text annotation.
- Support multi-plane reconstruction, three-view display and linkage through crosshair.
- The ability to 3D reconstruction and display 3D models.
- The ability to perform segmentation reconstruction of lung CT and support five views including sagittal view, coronal view, cross section, lung parenchyma model and sternum mode.
- Brain MRI analysis includes: skull dissection, gray matter segmentation, white matter segmentation, whole brain reconstruction, white matter reconstruction, gray matter reconstruction.

As a DICOM Viewer, the basic application of medical image 3D Visualization Web platform is to solve the needs of image viewing for clinicians. It can parse and display DICOM images at high speed. Allows doctors to view multiple sequences and multiple images for easy comparative analysis. It provides a variety of image manipulation tools so that doctors can be flexible, all-round observation of the image, while it provides measurement tools so that doctors can quantitatively analyze the target in the image. In addition, its annotation function can turn clinical data into data that can be used for deep learning model training. The schematic diagram of image browsing and annotation is shown in Fig. 7.

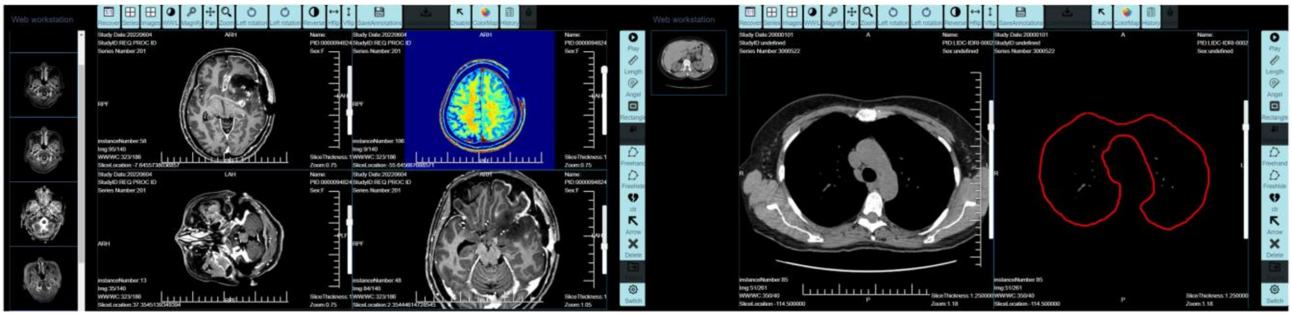


Figure 7. On the left side, four series are displayed, and different operations are performed respectively, including window width and window level adjustment, Pseudo color, rotation and magnification. On the right is a display of a lung manually segmented.

B. Application in Auxiliary Diagnosis of Pulmonary Nodules

In addition to the basic application of image viewing, it provides image post-processing functions to assist doctors in diagnosis. As shown in Fig. 8, this is the case of a patient with pulmonary nodules. The system displays cross-sectional, sagittal, and coronal images by multiplane reconstruction of lung CT. At the same time, the sternum and lung were reconstructed by lung parenchyma segmentation. Through five views, multi-modal information is displayed to assist doctors in diagnosis. The position, shape and size of pulmonary nodules can be clearly observed through the 3D lung model on the right of Fig. 8.

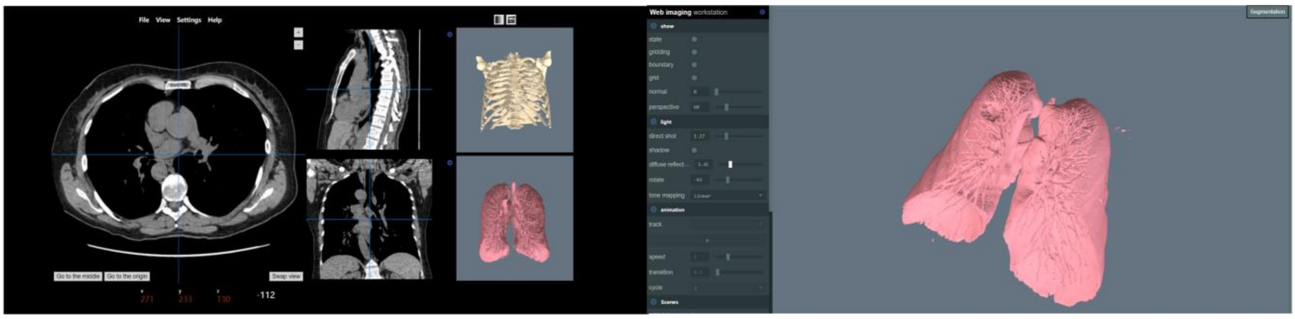


Figure 8. On the left is a CT series of the lung shown in five views, including cross-sectional, sagittal, coronal, sternal 3D model and lung 3D model. On the right is a 3D model of the lung.

C. Application in Preoperative Planning of Glioma

The system's analysis of brain MRI could help neurosurgeons with preoperative planning. Brain tissue is responsible for controlling various physiological activities of the body. The damage to brain tissue in the process of glioma resection will image the physiological activities of the body. In order to minimize damage, a comprehensive analysis of brain tissue and glioma should be performed before surgery. The system performs skull stripping, gray matter segmentation, white matter segmentation, and 3D reconstruction of the whole brain, gray matter and white matter. Doctors can determine the preoperative plan by observing segmented images and 3D models of different tissues The whole brain model on the right of Fig. 9 shows that the glioma area is a cavity, and the distribution of brain tissues around the glioma can be obtained by observing the cavity area.

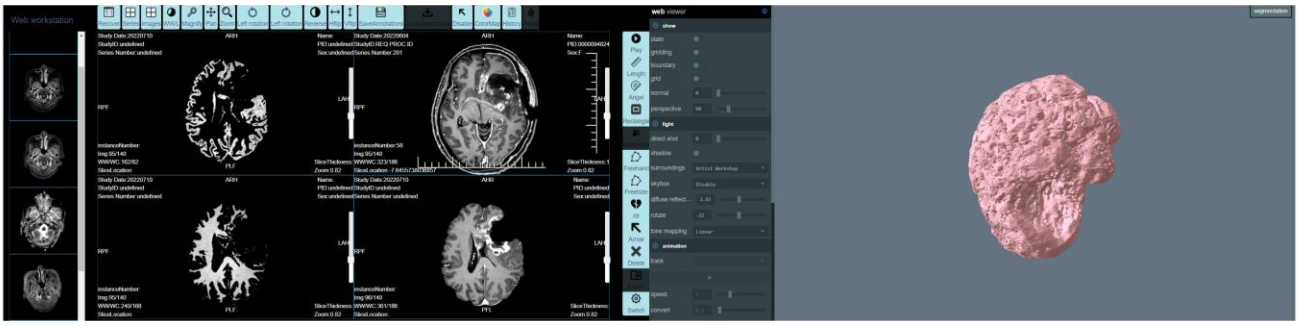


Figure 9. On the left is an MRI series of the brain and its processing including the original images, the skull stripping images, the gray matter segmentation images, and the white matter segmentation images. On the right is a 3D model of the whole brain.

IV. Experiment and Evaluation

In order to evaluate the performance of the software, we carried out quantitative tests and averaged them for each sub-task in the implementation of business functions. Here we pay special attention to the performance of various sub tasks of the image processing server in the process of reconstruction to model optimization. The test was performed in an Intel(R) Core(TM) I7-10870h CPU @ 2.20ghz 2.21ghz, 16.0 GB RAM (Random Access Memory), and NIVIDA RTX2060 environment. We listed three test cases and their indicators, including one lung CT data containing 242 DICOM instances, one MHA (MetaImage Medical Format) 3D data containing 262 CT slices of lung parenchyma segmentation, and one Brain MRI data in Nifti (Neuroimaging Informatics Technology Initiative) format containing 140 slices of skull stripping. Table II shows that an original model with a size of 236 mb (Megabyte) can reach 6.37 mb after transformation and optimization, and the compression ratio can reach 97.3%. Although model compression can cause some quality loss, we can adjust the vectorization parameters to get a visually acceptable model. We focus on rendering times because the rest of the time is imperceptible to the user. We can see that the render time for all three examples is less than 2.5s.

TABLE II. Three Test Cases and Their Indicators

Indicators\test cases	dicom	mha	nii
Size\mb	121mb	261mb	123mb
Reconstruction time\s	4.25s	3.30s	2.76s
Original model size\mb	236mb	142mb	100mb
Model conversion time\s	12.09s	7.53s	5.56s
glTF model size\mb	73mb	44mb	33mb
Model compression time\s	5.19s	3.28s	2.39s
Optimize model size\mb	6.37mb	3.63mb	3.09mb
render time\s	2.47s	1.74s	1.37s

V. Conclusion and Discussion

This paper presents a medical image 3D visualization platform, and describes its design architecture and implementation of key technologies. Finally, its features and application scenarios are summarized. As a web application, its rich image post-processing features and 3D visualization module make it not only a simple DICOM viewer, but also can be applied to more scenes, such as auxiliary diagnosis and preoperative planning, which is rare in other similar web applications (desktop applications tend to have more great features). It adopts the route of asynchronous reconstruction, optimizing, saving the model, and then rendering, which can greatly reduce the waiting sensation brought by real-time rendering to users. However, it also has the limitation of reducing the model's interactivity and occupying storage resources. Its distributed design architecture makes it highly scalable, which lays the foundation for our later development of new modules. For future development, we will develop new modules for different scenarios according to the needs of clinicians. For example, at present, Nerve physician have put forward demand for cerebrovascular analysis of MRA images. After investigation, using the vascular modeling toolkit VMTK [23] for vascular analysis is a good solution. In short, the medical image 3D visualization web platform is a software with clinical application value, and its subsequent development will also provide solutions for more clinical needs.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Shengyu Bai, Ling Ma and Huiqin Jiang conducted research and software development. Shengyu Bai wrote the paper. Chen Ma and Huiqin Jiang revised the paper. Xinjun Wang and Shaolong Zhou provided medical guidance. Hongyu Jiang provided the software running and testing environment. All authors had approved the final version.

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