

A web-based virtual reality environment for medical visualization

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Abstract—In this paper, we present a novel approach to integrating virtual reality (VR) into a web-based medical visualization framework. The framework supports visualization of volumetric data, such as 3D scalar fields acquired by a CT, MRI or PET scanners. To improve users' perception, understanding and manipulation of 3D volumes, we adapted the traditional 2D screen representation with support for visualization of data in a VR environment. By providing complete visual immersion, VR can help users to gain better insights and understanding of the visualized data. Our main goal was to allow users to view the medical data in VR and interact with it with hand-held controllers for better immersion and spatial perception.

In the paper, we present a novel approach to implementation of VR for medical imaging, which combines WebGL-based hardware accelerated web visualization with VR. This allows users to use the visualization framework with or without a VR headset by switching between "standard" and "VR" modes. Since visualization runs in a web browser, it is portable, easy to use on different devices and therefore accessible to a broad number of users. The visualization system was tested with real medical scans to assess its performance and usability.

I. INTRODUCTION

With the development of 3D scanners for medical purposes [1]–[3], physicians are getting large sets of radiological data about their patients. The data provides support for physicians with diagnosis, planning surgeries and even during surgeries. With better visualization, we could make their decisions easier and more confident.

Modern scanners usually give us data in form of 3D scalar fields. This data needs to be processed and displayed in a way that can be easily viewed by physicians. Usually, images are rendered on traditional 2D screens, but viewing 3D images on 2D screens can cause some problems with perception and display of the details, because these screens lack the depth perception, which is crucial for better spatial perception of volumetric data. It is harder to see specific details and it took longer to put them in the perspective, which is very important in medical domain.

There are existing applications, that can display data in 3D with pre-installed software and specific headsets [4], [5]. Very good example of a software that uses volume rendering and virtual reality combined is SpectroVive¹. It was developed at the University of Basel as part of the MIRACLE project².

¹<https://www.unibas.ch/en/News-Events/News/Uni-Research/Virtual-Reality-in-Medicine.html>

²<http://dbe.unibas.ch/public/dbe/research/FlagshipProject.html>

There are also many commercial products in field of VR in medicine: Immersive Touch³, Medical Realities⁴, Osso VR⁵, Surgical Theater⁶.

Apart from actual products, there are also many articles researching possibilities of using computer graphics and VR in medicine.

Virtual reality is becoming very important in medicine. An article [6] explains current and future use cases in this field. We have seen a big rise in popularity in recent years due to reductions in the cost of VR headsets and commercialization. An article also addresses a history of VR use in medicine.

In article [7] researchers presented benefits of using three-dimensional ultrasound imaging in the diagnosis of rental-onset skeletal dysplasia. Results clearly showed that physicians were able to score better in finding skeletal dysplasia when using 3D ultrasound, compared to using 2D ultrasound. We believe that with VR physicians will be able to get better results compared to viewing 3D ultrasound images on 2D displays.

Study about the user acceptance of the web-based distribution of radiology services was made in Western Australia [8]. There were many different opinions about the system, but on average they were satisfied with the approach.

Many applications and frameworks were developed for visualization of volumetric data. A good example is Exposure renderer [9], which is used for local visualization but lacks support for web and VR.

Researchers have also investigated the benefits of immersion in virtual reality for volume data visualization [10]. They concluded that VR platforms have untapped potential for exploring visualizations of volumetric data. They pointed out that the VR community needs empirical results to validate the claims of benefits of immersion for VR.

An article [11] named "Applications of Virtual Environments in medicine" shows us many possibilities of using VR in medicine. First health care applications of VR started in the 90's. In past decades there were huge advancements in both software and hardware, making VR experience more accurate and affordable. There is a huge interest in medicine for VR because it can be used in many situations such as medical

³<http://www.immersivetouch.com/>

⁴<https://www.medicalrealities.com/>

⁵<http://ossovr.com/>

⁶<http://www.surgicaltheater.net/>

education, surgical simulation and planning, virtual endoscopy, neuro-psychological assessment, rehabilitation and many other situations.

In contrast to approaches presented above, we present a novel web-based framework for medical imaging in VR. Our framework uses WebGL 2.0 for hardware accelerated web visualization with support for the VR. This allows users to use our visualization framework with or without the VR headset. It is also not limited to the specific headset and uses the same code base for all visualization purposes. Best of all, it runs in modern browsers, even on mobile devices. Currently supported browsers and platform are held in an updated list⁷.

The remainder of the paper is organized as follows: In Section II we present the developed system and its properties, in Section III we present the evaluation and results of the developed system and in Section IV we present the conclusions and give pointers for the possible future work.

II. THE DEVELOPED SYSTEM

The developed system presents an extension of Med3D framework with support for VR through use of WebVR application programming interface and integration of volumetric ray casting rendering technique for volumetric data visualization.

A. Med3D

Med3D [12] is an open-source web-based 3D medical data visualization framework (see Figure 1) based on NeckVeins Java framework [13]. It was developed as a platform independent tool for visualization of medical volumetric data. WebGL 2.0 library is used for exploiting the hardware accelerated graphics rendering in the browsers. The application enables remote collaboration between users [14], who can share data, view data annotations and can also communicate via integrated chat. The framework runs in all modern browsers and supports standard input devices such as mouse and keyboard. On top of that the framework also supports the 3D mouse and Leap Motion for navigation. The application is capable of displaying 3D mesh models (in form of .obj files) as well as mesh representation of 3D volumetric data (such as CT or MRI scans in form of .mhd files).

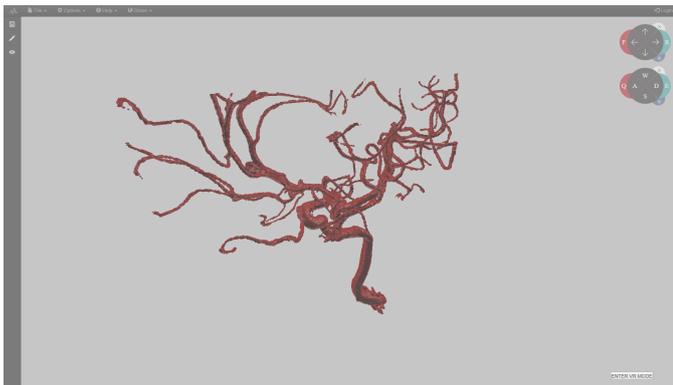


Figure 1. Med3D visualization framework.

⁷<https://webvr.rocks/>

B. Integration of VR

Since we want to display data in virtual reality and also make the application available through web browser we decided to use WebVR application programming interface [15]. The WebVR application programming interface provides support for exposing virtual reality devices (usually a head-mounted display) to web applications. We used this application programming interface inside Med3D in a way that is displayed in Figure 2.

1) *Using the WebVR application programming interface:* In the first step we query the application programming interface for available VR devices. In response we get list of references to available VR displays. We have to select a display on which we want to present the visualization to user. If we successfully obtained at least one VR display we can advertise VR functionality to the user in form of button for entering VR mode (see Figure 1 - bottom right of the screen). When the user clicks the button, the application requests presentation on the selected display. In the next step the application makes a method call `VRDisplay.requestAnimationFrame()`, to run the rendering loop at the correct refresh rate for the display.

Inside this loop, method call `getFrameData()` returns required data needed for rendering the current frame. Afterwards, the displayed scene is draw twice (first with parameters for left eye, second with parameters for right eye). When rendering the scene for both eyes is finished the result image has to be submitted to display in the headset. Because WebVR application programming interface is responsible for communication with VR devices (headsets) our framework does not have to deal with calls for specific headset.

2) *Additional modifications required in Med3D application:* Because we wanted to use existing rendering pipeline, we had to adapt the Med3D framework in order for the application to work in the desired manner. When the user requires rendering in VR, we obtain VR display parameters (e.g. rendering width, height, etc.). In each iteration of render loop we have to render the scene separately for left and right half of the display. Because each rendered image is narrower, we have to set correct aspect ratio. We also have to compute correct FOV, far and near plane from projection matrix and pass them to existing method calls. The application with enabled VR display is presented in Figure 3.

3) *Implementing VR controllers support:* For implementation of controllers we used Gamepad application programming interface⁸. It gives developers a way to access and respond to signals from controllers. Benefit of using this application programming interface is that it works with multiple controllers. Since it is still only experimental technology it might have some drawbacks. Currently there is also limited support in browsers, but it has broader support than WebVR. We used experimental game-pad extension GamepadPose to give users better experience in VR mode. The GamepadPose interface is very useful in our application, since it represents

⁸https://developer.mozilla.org/en-US/docs/Web/API/Gamepad_API

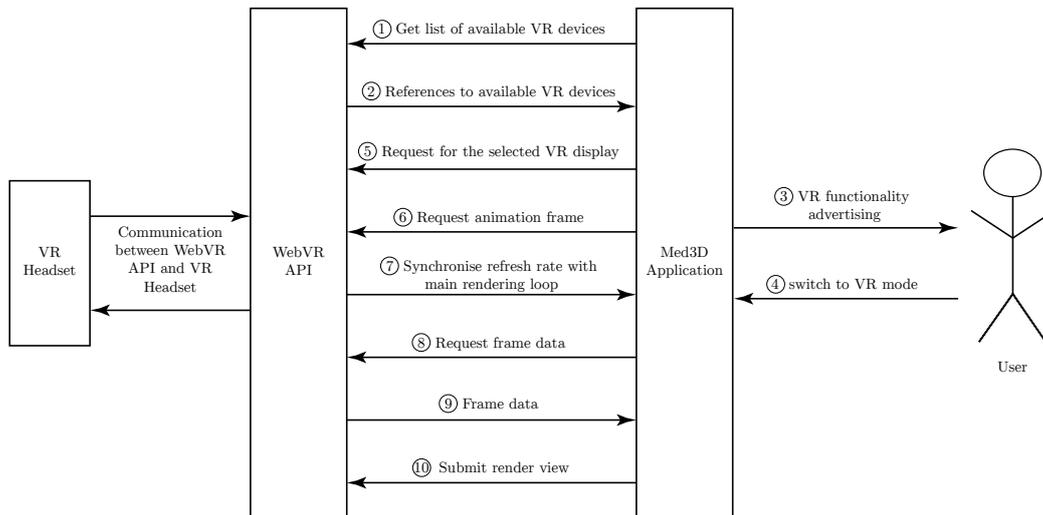


Figure 2. Diagram of WebVR integration in Med3D framework.

a pose of WebVR controller. It has many properties including orientation, position, acceleration, etc. Firstly we have to check if game-pad is connected to the computer. Afterwards, we make sure that game-pad is available and we query the game-pad object to obtain interaction data. We use controllers for the scene navigation.

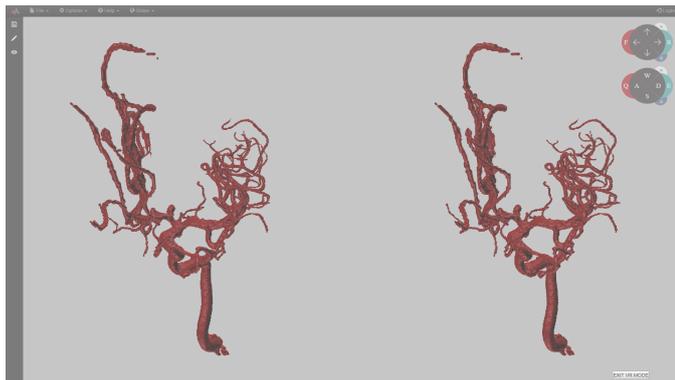


Figure 3. Visualization of data in VR mode.

C. Integration of volumetric ray casting

Volume ray casting [16] is an image based volume rendering technique which allows direct rendering of 3D scalar data without converting it to the mesh object. The implementation was developed as GLSL shader used in the standard Med3D framework rendering pipeline. The framework was adapted with support for sending larger 3D scalar data directly to GPU, setting the volumetric ray casting parameters and executing the rendering on the data in fragment shader as done in deferred rendering approach. The implementation also supports different ray casting techniques such as: maximum intensity projection, ISO surface rendering and alpha compositing.

All other Med3D functionalities were kept, such as scene navigation and other user interaction. The scheme of the indi-

vidual system components and their relationship is presented in Figure 4.

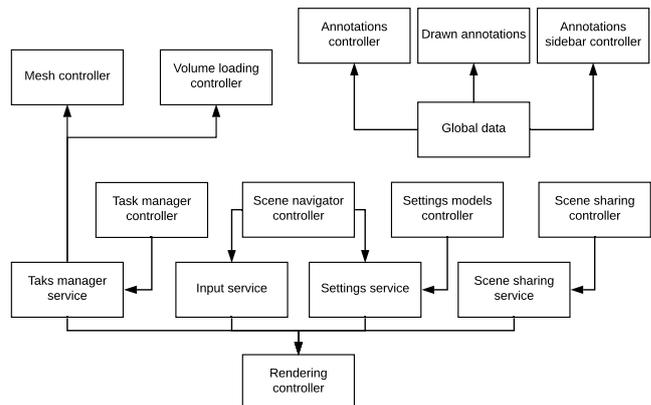


Figure 4. The system architecture and its individual components.

III. EVALUATION AND RESULTS

For quantitative evaluation we tested frame rates of ordinary rendering to the screen and rendering in VR mode. To eliminate dependency on specific headset we tested it with special plug-in⁹ for Google Chrome that emulates HTC Vive headset.

The application was tested on two computers. First was a HP laptop with Intel i7 (2.2 GHz) processor, 8GB RAM and AMD Radeon HD 8750M graphics cards. Average fps (frames per second) for ordinary rendering on screen is 26.860 frames per second. Average fps for rendering in emulated VR mode is 46.992 frames per second.

We tested application with the same model on another computer: Intel i7 (3.6 GHz), 16GB RAM and NVIDIA TITAN Xp graphics card. Average result here was for both

⁹<https://github.com/spite/WebVR-Extension>

normal and VR mode was approximately 60 fps. Reason for this is the browser limitation, which is 60 frames per second.

Frame rate is higher in VR mode for first system, but it is still too slow for high-quality VR experience. The goal of VR is to target 90 frames per second at all times to ensure good user experience of virtual reality. The hard limit of 60 fps is the downside of rendering graphics in web browsers.

IV. CONCLUSIONS AND FUTURE WORK

We developed a web application that allows visualization of mesh data and volumetric data in virtual reality. Its main purpose is to provide physicians with the better insight in the volumetric data obtained from 3D medical scanning (such as MRI, CT etc.). The main advantage of our such application is its accessibility. While most of the other applications (mentioned in the article) require specific software and hardware for displaying the data to users in virtual reality the presented application runs in the web browser and does not require any specific software (apart of the browser and software from your VR headset manufacturer). It also gives users freedom of choice, because they can use a headset of their choice or even use the application without the VR capabilities. Since this technology is quite new, there are certain limitations and weaknesses. Applications that run in the web browser usually cannot be as fast and responsive as native applications. There is also limited support for different web browsers as well as web browser limit of rendering 60 fps. All browsers do not support WebVR application programming interface yet and some headsets are limited to certain operating systems. With the development of the technology and predicted growth in the next years these limitations will gradually vanish.

In the future we will try to optimize implementation of VR functionality to make it faster and more user friendly. We believe that VR will play important role in the future of medicine and our improved application can be a good example. In addition to optimizing currently supported options for rendering there are still many techniques that we could implement in the future to make our application better and more user friendly.

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