Evaluation of 3D Slicer as a medical virtual reality visualization platform

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ABSTRACT

PURPOSE: There is a lack of open-source or free virtual reality (VR) software that can be utilized for research by medical professionals and researchers. We propose the design and implementation of such software. We also aim to assess the feasibility of using VR as a modality for navigating 3D visualizations of medical scenes.

METHODS: To achieve our goal, we added VR capabilities to the open-source medical image analysis and visualization platform, 3D Slicer. We designed the VR extension by basing the software architecture on VTK's vtkRenderingOpenVR software module. We extended this module by adding features such as full interactivity between 3D Slicer and the VR extension during VR use, variable volume rendering quality based on user headset motion etc. Furthermore, the VR extension was tested in a feasibility study in which participants were asked to complete specific tasks using bot the conventional mouse-monitor and VR method. For this experiment, we used 3D Slicer to create two virtual settings, each having an associated task. Participants were asked to maneuver the virtual settings using two approaches, the conventional method, using mouse and monitor, and VR using the head-mounted-display and controllers. The main outcome measure was total time to complete the task.

RESULTS: We developed a VR extension to 3D Slicer—SlicerVirtualReality (SlicerVR). Additionally, from the experiment we conducted we found that when comparing mean completion times, participants, when using VR, were able to complete the first task 3 minutes and 28 seconds quicker than the mouse and monitor method (4 minutes and 24 seconds vs. 7 minutes and 52 seconds, respectively); and the second task 1 minute and 20 seconds quicker (2 minutes and 37 seconds, vs. 3 minutes and 57 seconds, respectively).

CONCLUSION: We augmented the 3D Slicer platform with virtual reality capabilities. Experiments results show a considerable improvement in time required to navigate and complete tasks within complex virtual scenes compared to the traditional mouse and monitor method.

KEYWORDS: Virtual Reality, 3D Slicer, Visualization, Segmentation, Medical Training, Procedural Planning, Open-source.

1. INTRODUCTION

Virtual reality (VR) is a technology that places users in a fully immersive and intractable virtual environment; making it useful in many different applications. In recent years, VR has seen a rapid expansion both in commercially available hardware as well as software applications. The decline in cost of computing power and production of VR hardware has attributed to this expansion. VR systems vary in complexity. Although all VR systems consist of head-mounted-display (HMD), the most complex systems typically consist of a HMD, hand controllers, and a tracking device(s). These more complex systems provide the most immersive experience by providing high performance visual rendering, accurate positional tracking and intuitive controls for interaction with the virtual environment. Examples of these systems include the *HTC Vive*, *Oculus Rift*, and the many headsets that use Windows Mixed Reality.

More complex VR systems employ tracking methods that are accurate and fast, which is vital for truly immersive experiences. Some of the available VR systems, like the *HTC Vive*, utilize infrared tracking systems to track the headset and controllers. The trackers can create up to a 21 m^2 space of tracked area[1] in the physical world that serves as the boundary for the virtual environment. However, VR currently faces challenges in use and accessibility. VR systems lack dexterity and agile tracking. The controllers do not accommodate fine motor movements, which limits the type of tasks that are possible and effective in a virtual environment. VR systems also require large empty spaces to operate effectively. Additionally, both the VR system, and a computer with adequate computing power is still relatively expensive for individual use. There are also issues of user motion sickness which have prevented prolonged stay in the virtual environment [1]. However, despite these issues, VR is a highly useful technology that can be utilized

[1] https://www.digitaltrends.com/virtual-reality/oculus-rift-vs-htc-vive/

by various applications. The current most popular application of these technologies is in gaming and entertainment and is the driving application of VR development.

As of recent, however, many have looked to expand the use of VR for different applications in the medical field, such as to train medical professionals, plan surgical interventions, and better visualize complex structural relationships. For example, Seymour et *al*. [2] has shown significant improvement in performing laparoscopic cholecystectomy when VR systems were used to train prior to the operation. VR is promising as a training instrument for surgeons because it increases the availability of hands-on training at a relatively low cost. Moreover, VR will create a new medium for medical professionals to visualize target anatomy and examine the visualization with stereoscopic capabilities. A study by Frajhof et *al*. [3] showed that modeling the target anatomy in VR assisted surgeons in planning and executing the operation. However, currently there is a lack of free or open-source software for use in the medical field.

In this study we propose to extend 3D Slicer, open-source medical image analysis and visualization platform, with VR capabilities to be used as a medical VR visualization platform. 3D Slicer is a well-established tool in assisting medical professional in an array of clinical applications [4]. By extending 3D Slicer, users will have access to data management, visualization tools, segmentation tools and many other functions. 3D Slicer also allows users to tweak and create functions to suit their individual needs. The platform is also very well documented for both developers and users. Therefore, we expect users to be able to conveniently create medical scenes to show in VR. The goal of this study is to assess 3D Slicer as a platform for VR (1) and the feasibility of its use in the medical field (2). We propose this extension to address the lack of open-source VR software that is flexible and extensible for use with medical professionals.

2. METHODS

2.1 Requirements

The aim of our VR extension is to serve as a basis for VR applications for visualization and interaction with medical images. The key requirements and priorities for this VR extension are: 1. it must have intuitive controls to make scene navigation effortless; 2. it must maintain high performance rendering to deal with issues of motion sickness and user comfort; 3. it must have customizable options to best suite individual experiences; 4. it must be able to conveniently import and visualize medical imaging data; 5. the platform must be free with a permissive license and easily accessible; 6. easy to setup; 7. it must be versatile and easy to build upon.

2.2 Platform

SlicerVR is built using 3D Slicer as its platform. 3D slicer is an open-source medical image analysis and visualization platform (Figure 1). SlicerVR utilizes the many integrated tools and features of 3D Slicer to show 3D medical scenes in VR. 3D Slicer offers features such as image segmentation, registration, visualization, and analysis. 3D Slicer has capabilities of visualizing 3D renderings of target anatomy from various medical imaging modalities, such as Magnetic Resonance Imaging, X-ray, Ultrasound and Computed Tomography. This platform has seen continual development and is now applied to a wide range of clinical and research applications. Additionally, 3D Slicer is modular and extensible, which allows developers to create modules in downloadable extensions that add considerable feature sets to 3D Slicer core. In addition, both 3D Slicer and the SlicerVR extension are fully open-source, redistributable with a permissive license, thus adhering to requirement 5.

2.3 Design

3D Slicer provides a plug-in mechanism that allows for quick development of function-specific modules. We design our VR software as a module that can be distributed as an extension, available to install within 3D Slicer's Extensions Manager. Our work consists of developing VR core logic, connection to VR hardware, and integration with 3D Slicer. We utilize VTK [5] for VR rendering and hardware connection. VTK uses OpenVR, a software development kit which supports the connection to VR hardware. By utilizing OpenVR, the 3D Slicer VR extension can be used on any OpenVR-compatible VR system, such as the *HTC Vive* and the *Oculus Rift*. Figure 2 demonstrates the proposed software architecture. We propose to show, in the virtual environment, any scene that can be imported or created, and rendered in 3D Slicer. Also, simple, one-click, importing of the 3D Slicer scene to the virtual environment is also desired, as to maintain ease-of-use.

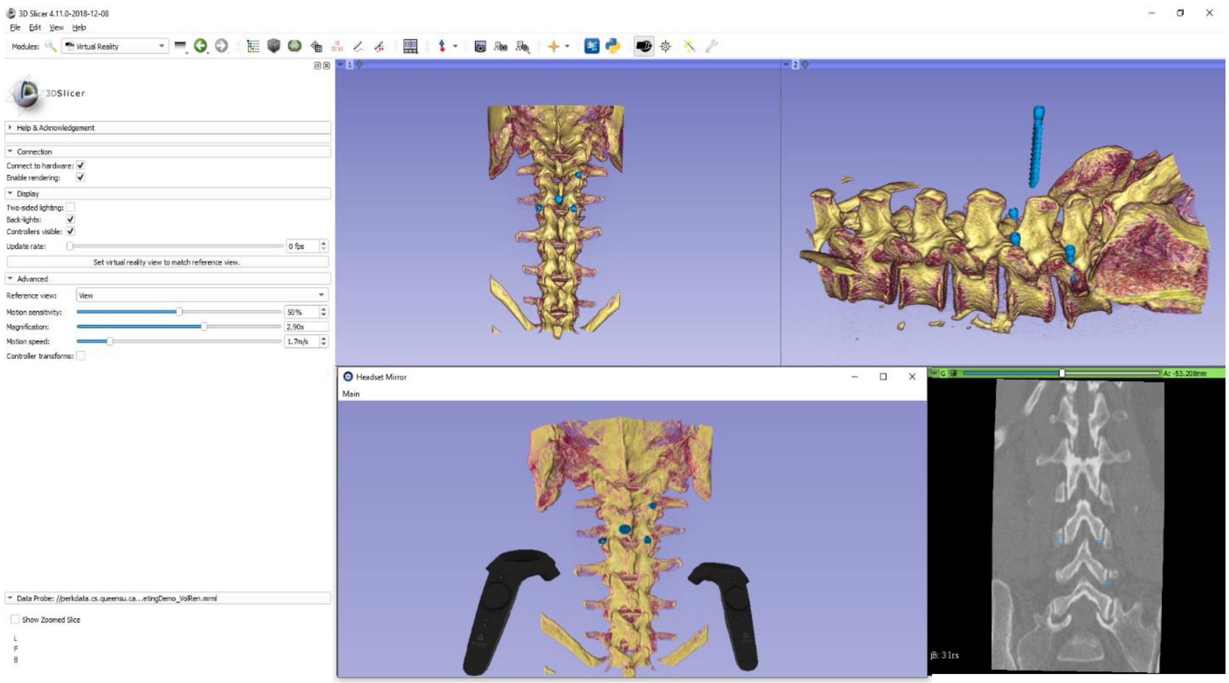

Figure 1: 3D Slicer software running on Windows operating system

In addition, we implement progressive rendering to find a balance between render quality and performance to decrease motion sickness felt by users, which stands as a barrier to prolonged VR use. Issues of motion sickness in VR are often caused by disjointed render quality, which causes a discrepancy between users' sensory inputs and what is being projected in the HMD. To address this and fulfill requirement 2, we maintain high and consistent refresh rate, by lowering render quality when quick user movements are detected. When user motion is no longer detected, render quality is returned to a maximum. Users will also be able to use VR controllers to grab and reposition objects in the scene which is needed for further examination of the environment (Figure 3). Furthermore, the ability to navigate the virtual scene will be designed with intuitive hand motions and controls in mind. By doing so, we hope to decrease the learning-curve associated with traditional mouse-monitor methods of navigation, which require users to learn different mouse-keyboard combinations and hotkeys. In addition, we fulfill requirement 3 by designing controls to manage framerate, enable and disable hardware connection, and manipulate physical aspects of the virtual scene itself. Figure 4 demonstrates the user interface for the extension.

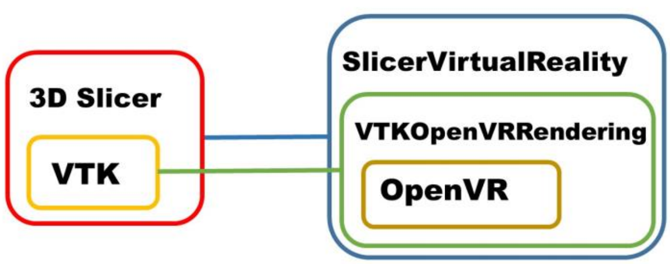

Figure 2. Software architecture diagram for SlicerVirtualReality

Figure 3: The *HTC Vive* Head-Mounted-Display and controllers being used to navigate a virtual scene that consists of a spine volume rendering used for pedicle screw insertion.

2.6 Experimental setup

We propose to test the feasibility of utilizing VR for the visualization of three-dimensional (3D) rendering. To do this, we test the participants' ability to complete tasks that require them to maneuver through complex virtual environments. Our experiment consists of two tasks that compare the stereoscopic display and immersive interaction of VR, to viewing 3D images on a flat two-dimensional (2D) monitor screen. The first task consists of a scene that is designed to be difficult to navigate. This task forces users to traverse the entire scene and requires constant reorientation. We design the experiment in this manner to examine how users will navigate unfamiliar scenes. The scene consists of eight hollow cubes with colored integers, one to eight, inside the cubes (Figure 5-1). The cubes have a circular hole on one of the sides, which participants must navigate towards, to identify the number and its color (Figure 5-2). These cubes are spread throughout the scene, in a non-uniform manner, to cover much of the traversable environment. The cubes are also oriented at random along all three axes. This placement of the cubes makes certain that the participants will have to traverse most of the scene, as well as reorient their view often. It also circumvents users from completing the task

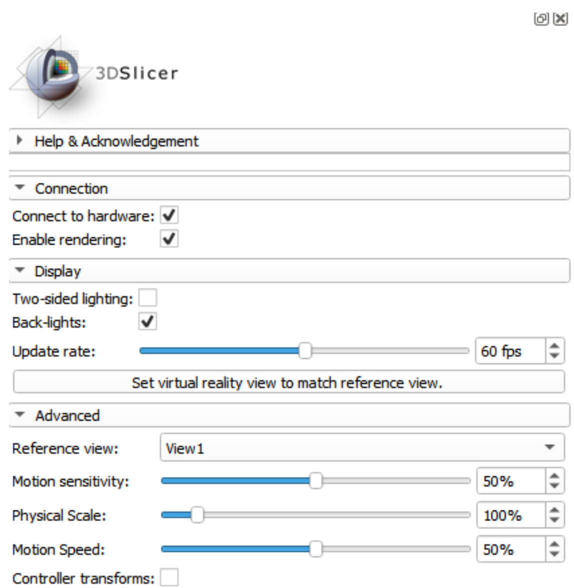

Figure 4. The user interface panel for the Slicer Virtual Reality module in 3D slicer

using simple movement patterns, such as moving along one axis to the next cube. By asking participants to identify the integer in combination with its color, it ensures that participants will navigate close enough to the hole in the cube such that they can read what integer is present, and that participants must visit all of the eight boxes individually, as to avoid false positives.

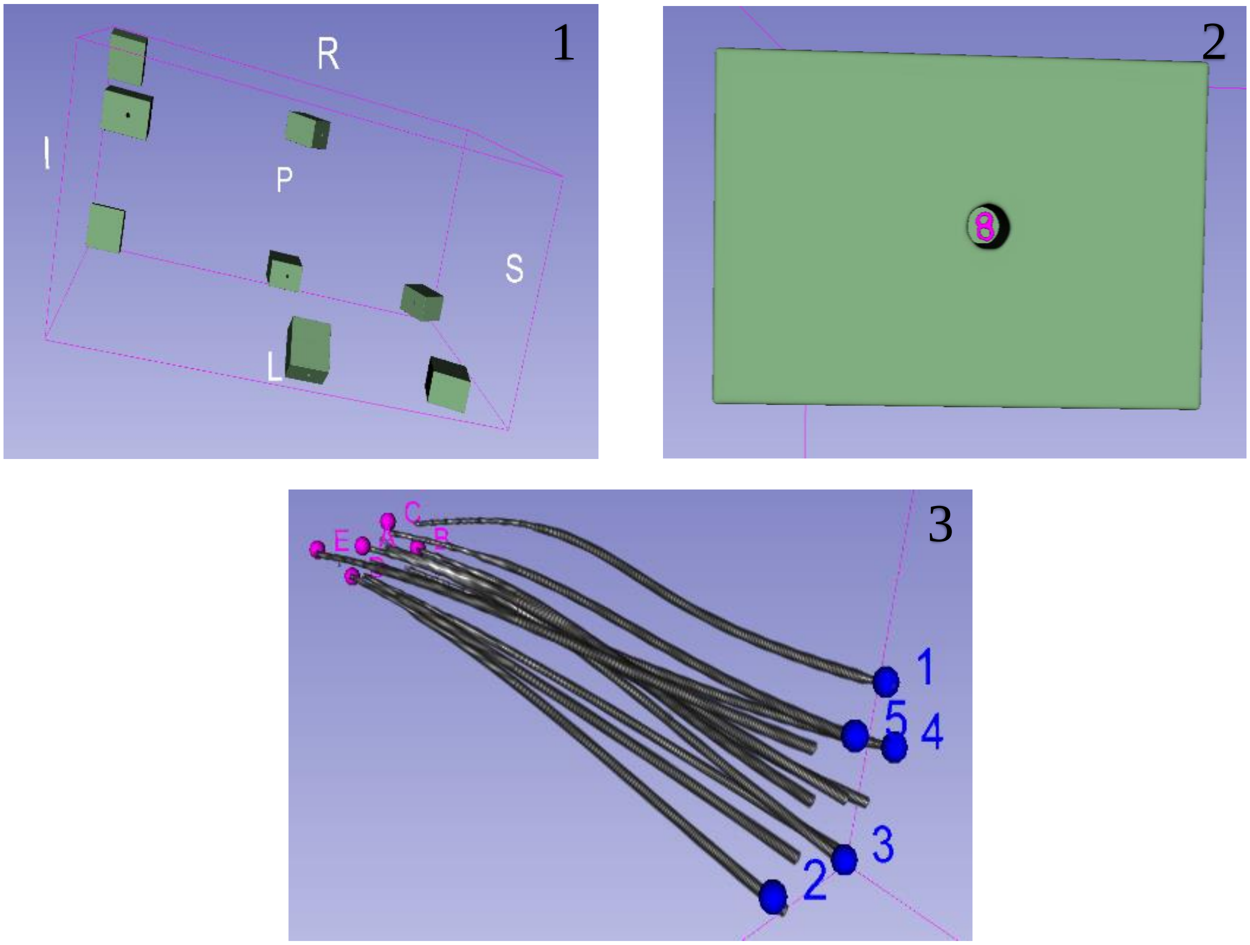

Figure 5: *5-1:* Volume renderings of bracytherapy phantom using the Volume Rendering tool in 3D Slicer with only the catheters visualized. *5-2:* Eight cubes created by the Segment Editor tool in 3D Slicer. *5-3:* The integer eight in pink found inside one of the eight cubes.

The second task consists of a 3D rendering of a brachytherapy phantom, with only the catheters in view (Figure 5-3). There are 11 total catheter renderings in this scene. Five of these catheter renderings are labeled on either end. One end of the catheters consists of integer labels, seen in blue, and the other end consists of letter labels, seen in pink. The task requires participants to follow the catheters from one end to the other to identify what letter corresponds to each integer. We chose this scene because the catheters are difficult to follow from one end to the other, as the catheters are spatially near one another, and intersect in some regions. This means that participants will not be able to accurately identify the correspondence of the ends of the catheters from one view. Instead, participants will have to traverse along each of the labeled catheters from one end to the other. Participants may also have to reorient themselves, and rotate their view, in order to label each catheter. Both these tasks are done twice—once with mouse and a traditional 24" monitor, and once in with the stereoscopic view of the *HTC Vive's* tracked HMD and controllers. Both tasks are completed, first, using the mouse-monitor modality, and then using VR. For both tasks, two slightly varying scenes are created in order to circumvent participants from memorizing answers. These tasks are timed until completion.

3. RESULTS

Results in Figure 6-1 show a significant decrease in the total time needed to navigate to and identify the color each of the eight integers in the box task. The mean time required for completing the task using the mouse and monitor modality was 7 minutes and 52 seconds. Using the immersive environment offered by VR, it took participants a mean time of 4 minutes and 24 seconds. Furthermore, for the box task, the number of revisits was also recorded. This is when participants navigated to a previously visited box. The mean amount of revisits for the mouse-monitor modality was considerably higher when compared to VR (11.6 re-visits *vs* 5, respectively). Figure 6-3 illustrates the amount of revisits for each participant.

Results in Figure 6-2 corroborate the results in Figure 6-1. With but one exception, all participants required less time to complete the task. The mean time required for the mouse-monitor navigation was 3 minutes and 57 seconds, compared to VR's 2 minutes and 37 seconds.

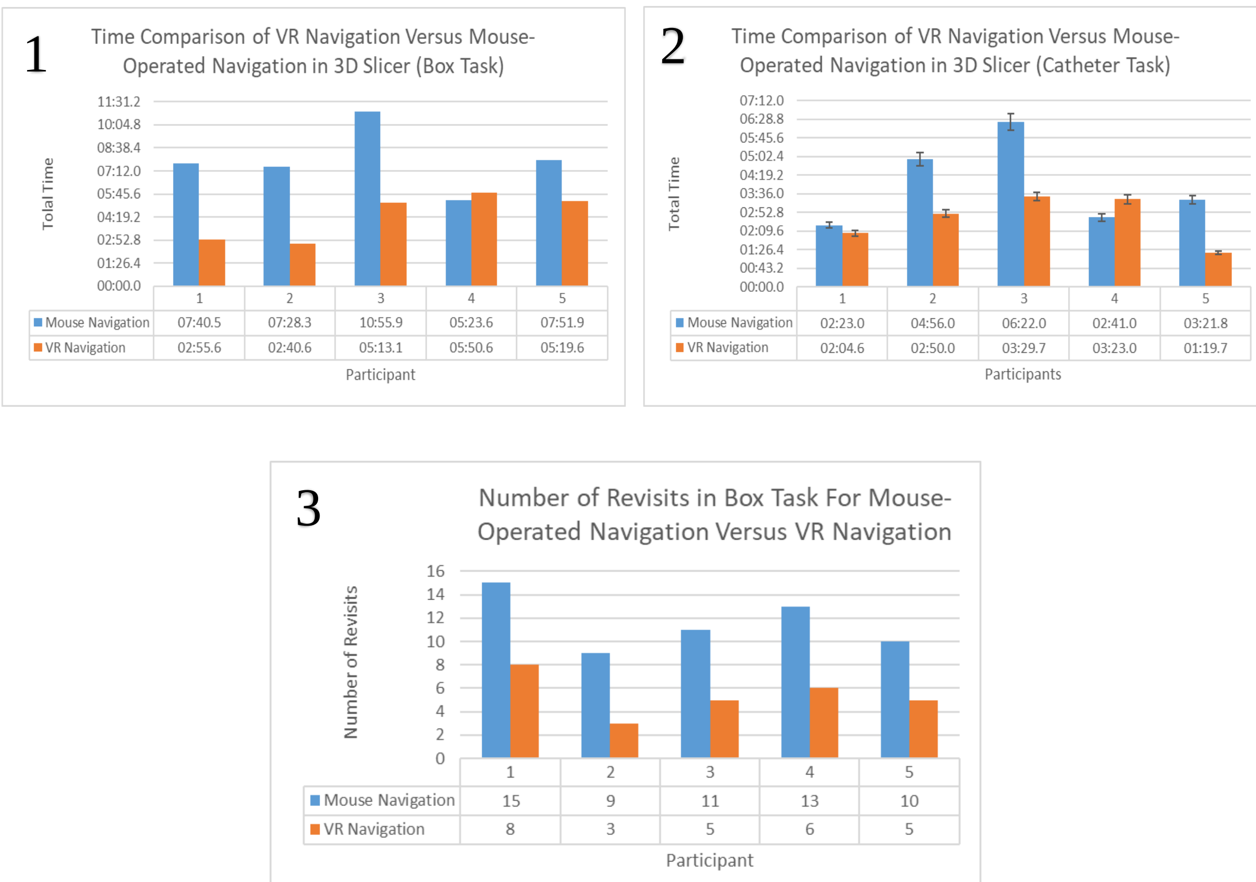

Figure 6. 6-*1:* Time required to complete box task using mouse-monitor modality compared to VR modality. *6-2:* Time required to complete catheter task using mouse-monitor modality compared to VR modality. *6-3*: Number of times a cube was revisited during the box task when comparing mouse-monitor modality to VR modality.

4. DISCUSSION

We designed and implemented SlicerVR, which will address the lack of open-source VR software that is flexible and extensible for use by medical professionals. We implemented this extension in C++ to extend 3D Slicer and can be installed from Extension Manager. In addition, once the extension is installed, it requires the click of one button to show a scene in VR, making it easy to set up. SlicerVR shows promise in being state-of-the-art virtual reality software for purposes pertaining to the field of medicine. Currently, SlicerVR can conveniently show any scene that can be rendered in 3D Slicer in a virtual and intractable environment, which fulfills requirement 4. Users can navigate these scenes and utilize the perception of three-dimensions given VR's stereoscopic capabilities. Spatial relationships of 3D objects and depth perception are improved when compared to the 2D monitor [6]. Sense of a user's spatial orientation within the scene is improved in VR as well. Additionally, translations and rotations can be applied to any object renderings, allowing users to expand their perspectives of complex structures. These advantages provided by VR will help improve current systems used in the medical field for training and procedural planning. Prolonged use of VR has been limited by motion sickness. Therefore, SlicerVR finds a balance between performance and visual quality. When quick user motion is detected, SlicerVR compromises render quality in order to maintain performance speed. This makes the immersion more fluid, thus improving user experience by addressing the issues of motion sickness. Additionally, users can customize certain aspects of the virtual environment and the hardware to optimize an individual's experience. These features will be important as applications of VR in the medical field will likely require relatively prolonged stays in VR.

The decreased amount of time required to complete these tasks using VR can be attributed to its intuitive nature. Using VR, participants were not required to remember mouse clicks and keyboard combinations to navigate the scene effectively as they desired. With VR, the participant only had to point the controller in the direction the wish to travel and press one button. The VR extension also allowed participants to scale and rotate the objects in the environment with ease. The controls involve a combination of natural hand motions and pressing one button. Additionally, the immersive environment of VR, and the capability of stereoscopic view, allowed users to move their head around the structures as they would naturally do in the physical world. This, when compared to moving in unnatural ways around the 3D objects rendered on a 2D monitor, indicated that navigating using VR was more intuitive, fulfilling requirement 1. The advantage of the stereoscopic capabilities of VR is corroborated by the results in Figure 6-3, where participants using VR experienced less revisits. Participants were able to complete the task without requiring as much reorientation when compared to mouse-monitor. This indicates that participants had a better understanding of their surroundings in the 3D environment. The increased mean of revisits in the mouse-monitor modality also contributed to the longer completion times seen in Figure 6-2.

One point worth discussing is the outlier – participant 4. This participant required less time to complete both tasks using the mouse navigation. This could be because this participant is an experienced user of software similar to 3D Slicer, and was very comfortable with the keyboard-mouse combinations, whereas it was their first interaction with VR.

5. CONCLUSION

Our work added VR capabilities to 3D Slicer. This extension can show medical scenes created in 3D slicer on any OpenVR-compatible VR systems. The advantages of using 3D Slicer are evident in the available tools that can be used to create an array of different medical scenes. Additionally, our experiment results demonstrated the usefulness of VR in traversing medical scenes in comparison to mouse-monitor methods.

6. ACKNOWLEDGMENTS

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