BrainWatch Software for Interactive Exploration of Brain Scans in 3D Virtual Reality Systems*

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Abstract— **The ability to view medical images as 3D objects, which can be explored interactively, has now become possible due to the advent of rapidly emerging virtual reality (VR) technologies. In the past, VR has been used as an educational tool for learning anatomy, a visualization tool for assisting surgery, and a therapeutic tool for rehabilitating patients with motor disorders. However, these older systems were either expensive to build or difficult to acquire and use. Exploiting the arrival of new consumer devices such as the Oculus Rift that are now affordable, we have developed a software application called BrainWatch for VR ready computers to enable 3D visualization and interactive exploration of DICOM data sets focusing on PET and MRI brain scans. BrainWatch software provides a unique set of 3 approaches for interacting with the virtual object which we have named the observatory scenario with an external camera, the planetarium scenario with an internal camera, and the voyager scenario with a mobile camera. A live interactive demonstration of BrainWatch VR with the Oculus Rift CV1 will be available for conference attendees to experience at EMBC 2017.**

I. Introduction

Most humans rely on their sense of stereoscopic vision to understand objects and their relation to one another in 3D space. Ideally, for viewing brain scan data and the complicated structures of the brain, 3D imaging would be preferred, but many of today's common methods involve 2D imaging. Traditional methods for viewing PET and MRI brain scans include cross-sectional 2D planar images (in axial, coronal, and sagittal views), stereotactic surface projections as 2D planar images, and maximum intensity projections as pseudo-3D rotating volumes. However, these traditional methods represent only 2D imaging with either actual 2D images or 2D projections of simulated 3D volumes instead of more realistic 3D imaging. In order for humans to have a true 3D understanding of a 3D object such as the complex organ of the brain, a new approach should be developed and used in practical applications.

Virtual reality (VR) technology with headset devices, such as the Oculus Rift [1], provide a new approach for 3D spatial imaging with a growing market of systems for consumer use. VR gives the user the ability to move and interact with objects within a 3D virtual reality space in a seemingly real and physical way. VR systems may comprise head mounted devices that include 3D spatial audio, stereoscopic lenses and displays, along with head position and orientation tracking, all of which enables the associated software to process and update the experienced visual and auditory data streams according to the user's head movements. This technology can be further enhanced by hand tracking systems, whether using an infrared sensory array such as the Leap Motion or hand tracking devices such as the Oculus Touch and HTC Vive Touch controllers. Adding the tracking of hand movements supports more realistic interactions by the user such as physically reaching and virtually touching an object. A similar approach to VR, called Augmented Reality (AR), attempts to add digitally to reality by overlaying 3D images in the surrounding environment that can be experienced using tracking devices similar to those for VR. While AR is akin to VR in many ways, AR does not completely dissociate and isolate users from the physical world around them, whereas VR blinds users to this physical world and transports them to a virtual world.

Many non-entertainment applications for VR and AR headsets have already been developed. Reported applications include 3D sculpting [2], physical therapy [3], and surgical training [4]. VR can simulate surgical situations and provide practice for students in an educational context. Surgical simulations for neurological applications have been built using AR but require expensive hardware [4]. VR has enabled physicians to view a deeply embedded tumor which would have otherwise not been seen [5]. Immersive VR has also allowed investigators to interact with 3D brain scans [6].

In recent years, the quality and availability of these VR and AR systems have improved while the cost has been reduced enough to deliver consumer devices at affordable prices. Prior to these developments, VR and AR headsets often failed to sell due to their poor quality and expensive prices. Some investigators were able to build customized devices or otherwise obtain higher quality devices, but use of these systems was limited to their specific projects.

Currently available state-of-the-art consumer devices now include the Oculus Rift Consumer Version 1 (CV1), HTC Vive, Sony's PlayStation VR and Open Source VR, all of which cost less than $1,000. AR devices remain in development and are not as widely available as VR devices. However, the Microsoft HoloLens can be purchased in a developer prerelease form at a cost of $3,000. With the improving availability of both VR and AR systems, new applications can be built now to experience 3D brain scans that would enable the user to view, explore and interact virtually in a 3D environment generated from a volumetric set of planar slices obtained from tomographic imaging.

We report the successful development of our software

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called BrainWatch VR that transforms brain scans from standard DICOM format to a format necessary for visual exploration with the Oculus Rift head mounted display device and virtual reality system. The Oculus Rift system and BrainWatch VR software facilitate visualization and interaction with a representation of the brain by allowing the user to move around both the interior and exterior of the brain representation. BrainWatch VR software serves as a tool that can support educational and research applications now, and eventually clinical applications in the future.

II. Methods

Software for the BrainWatch VR project has been developed as an executable application built with Unity Technologies Unity3D v5.6 for Microsoft Windows, initially for use with the Oculus Rift CV1 VR system. Software development in Unity3D v5.6 interfaces with the Oculus Rift runtime v1.6 and software development kit v1.11.0. The Oculus Rift CV1 requires a VR ready computer and thus depends on a workstation which has the minimum specifications of an Intel i5-4590 CPU, nVidia GTX 970 or AMD R9 290 graphics card, 8GB of RAM, 3 USB 3.0 ports and 1 HDMI video connector. Software development for the Oculus Rift CV1 can be pursued in a variety of programming languages including C++, C#, and Java, but proceeds more easily and efficiently when conducted with an existing animation and graphics engine such as Unity3D [7].

The BrainWatch VR software application starts with set up on the computer in a user menu (see Figure 1). After loading and processing the DICOM folder of files for the brain scan slices, the user then renders the image data set both to the Oculus Rift CV1 headset and also to the computer display for reference by viewers other than the user wearing the headset. From a programming perspective, our application software BrainWatch uses the Fellow Oak DICOM Library [8] to load DICOM data sets from files to C# code object, and then uses the Oculus Rift Unity Assets, the Oculus Rift SDK and Oculus Rift Runtime for processing, rendering and display. The software has been developed to load the brain scan DICOM data set from a folder location on the computer, converts each brain scan slice into a texture2D object as a part of a larger texture2D array in Unity3D, processes the texture2D array into a 3D volume which is then rendered to the Oculus Rift via a raycasting algorithm [9] modified for use with Unity3D.

Movement within the Oculus Rift displayed virtual environment was designed to be more natural and operates relative to the direction of the user's natural gaze. The user's head position with directional gaze in space are tracked by the Oculus Rift CV1 headset. Together with head position and movement in combination with a few keyboard controls, the user can effectively move forward, backward, and to each side within the virtual environment displayed stereoscopically on the left and right eye lenses of the headset. In order to accommodate movement in 3D space both inside and outside the rendered object, the rendered volume is clipped dynamically to match the movement of the user's perspective in relation to the object.

When designing an application for virtual reality with the goal of viewing and exploring an environment containing visualized objects, there are a number of different factors which come into play in terms of user control. In such an application, there are two entities which can be subjected to programmatic control: the virtual camera (i.e., the user's perspective) and the visualized object. Each entity's position and orientation in space can be separately controlled in a number of different ways including the following alternatives: fixed position and orientation, fixed position with changing orientation, movement along a specific direction, rotation about a specific axis, and omnidirectional movement. This concept of analyzing the VR environment with visualized object and camera perspective by orientation and position in space can be applied to other viewing methods as well. For example, traditional methods [10] of viewing maximum intensity projection (MIP) displays can be described as viewing a pseudo-3D object rotating on a vertical axis in a fixed position while the camera's position and orientation remain fixed. A systematic analysis of the different possibilities yields the scenarios and unique viewing perspectives summarized in Table I including those that we have named the observatory, planetarium and voyager scenarios.

III. Results

Our BrainWatch software has been successfully developed and subsequently tested by users who were either naive to or experienced with VR. Testing was performed qualitatively by 20 different users comprising a focus group on a variety of VR enabled workstations using the same Oculus Rift CV1 device. Users ranged in age, experience, and field from students to technologists and clinicians. The aim of testing was focused on analysis of the capabilities of the software, users' experience of the different possible viewing scenarios, and assessment of users' overall reactions and impressions. From Table I, Scenarios 1–3 were developed fully for use with the Oculus Rift headset for which Scenario 3 resulted in the greatest positive response from users. Examples of screen shots for Scenarios 1–3 can be seen in Figures 2–4, respectively. Scenarios 4–6 are also available for use within the application by selecting Scenarios 1–3, and correspond to the computer display versions of Scenarios 1–3 without VR and without VR headset control.

More experienced users testing the software commented on two general issues. A few users who tested Scenario 4, which is the scenario most analogous to a more traditional MIP animation, felt that Scenario 4 even when not using the Oculus Rift headset was better than commercially available MIP viewers. This reaction was best attributed to the user's control over viewing the object (ie, managing its speed and direction of rotation) in comparison to traditional MIP viewers that lack such controls. Traditional MIP viewers usually generate a short animation or cine which displays the viewed object rotating in a specific direction at a constant speed. Other users wondered how much easier it would have

TABLE I: Scenarios and Viewing Modes for BrainWatch VR

Scenario			Object		Camera	
Number	Name	Practical	Position	Orientation	Position	Orientation
1	Headset Observatory	yes	Fixed	RotAxis (K)	Fixed (Outside)	Omnidir (H)
2	Headset Planetarium	yes	Fixed	Fixed	Fixed (Inside)	Omnidir (H)
3	Headset Voyager	yes	Fixed	RotAxis (K)	Omnidir (H)	Omnidir (H)
4	Computer Observatory	yes	Fixed	RotAxis (K)	Fixed (Outside)	Fixed
5	Computer Planetarium	yes	Fixed	Fixed	Fixed (Inside)	Fixed
6	Computer Voyager	yes	Fixed	RotAxis (K)	Omnidir (H)	Fixed
7	Traditional MIP	yes	Fixed	RotAxis (C)	Fixed (Outside)	Fixed
8		no	Fixed	Fixed	Fixed	Fixed
9		no	Fixed	Fixed	MovAxis (H)	Omnidir (H)
10		no	MovAxis (K)	Omnidir (K)	Fixed	Fixed
11		no	Omnidir (K)	Omnidir (K)	Omnidir (H)	Omnidir (H)

Legend: K – user controlled via Keyboard; H – user controlled via Headset; C – automated via Computer; RotAxis – rotation about axis; MovAxis; movement along axis; Omnidir – Omnidirectional change of position or orientation; Inside/Outside – position of camera perspective in relation to visualized object.

been to learn brain anatomy with 3D VR instead of 2D cross-sectional images and diagrams, and expressed a desire to use the VR software for training their students.

Because development of BrainWatch focused initially on proof of concept and testing software implementations with viewing scenarios, additional preprocessing methods to increase or decrease image resolution and/or to denoise the images have not yet been applied and tested systematically for all brain scans studied. Due to the absence of these image data preprocessing steps, some image processing artifacts have been observed including pixelated rendering and oddly stretched images for some brain scans. These artifacts occurred when rendering unmodified data sets with sizes smaller then 256 x 256 x 256. Subsequent development tests to address these artifacts utilized data sets from the Alzheimer's Disease Neuroimaging Initiative (ADNI) database which were then preprocessed in MATLAB 2017a with functions for 3D data set resizing. These preprocessing steps resized and/or padded the data set to be cubic and isometric based on the DICOM pixel size metadata tag. As an example, non-cubic data sets of size 256 x 256 x 128 with non-isometric voxels at 1 x 1 x 2 mm were transformed to cubic data sets of size 256 x 256 x 256 with isometric voxels at 1 x 1 x 1 mm.

A video demo of BrainWatch VR software can be viewed at https://www.bhavi.us/BrainWatchVR.

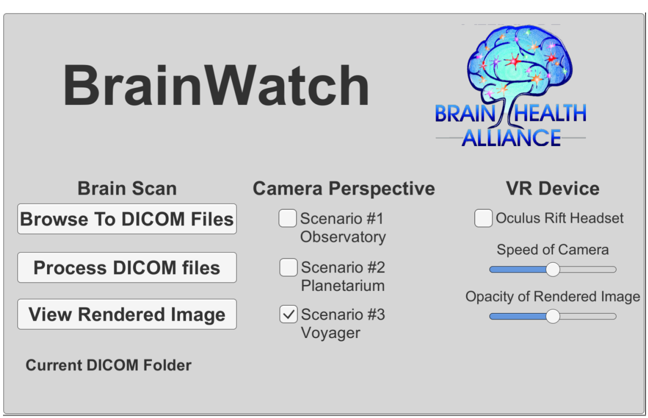
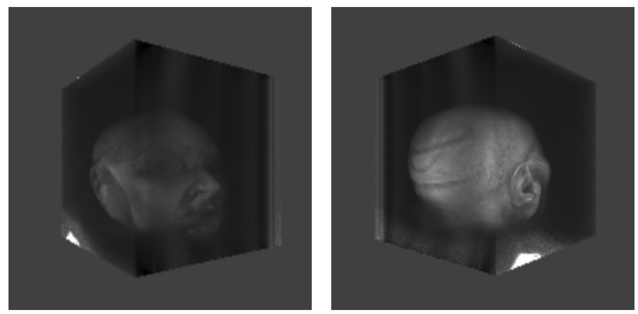
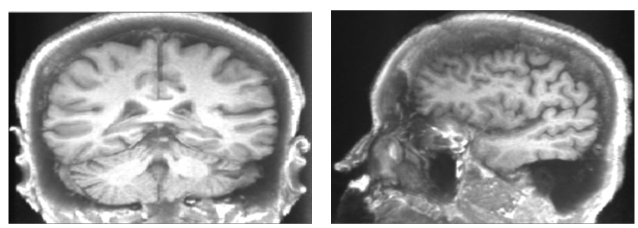


Fig. 1: User interface for BrainWatch VR Software



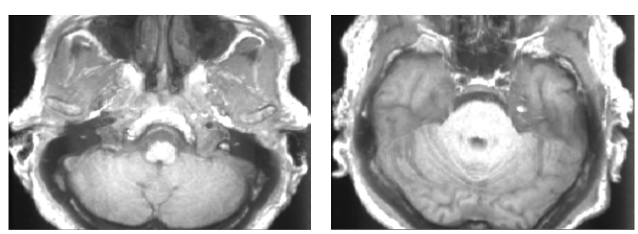
(a) Front of rendered volume (b) Back of rendered volume

Fig. 2: Scenario 1 – Observatory with external camera



(a) 0° rotation of volume (b) 125° rotation of volume

Fig. 3: Scenario 2 – Planetarium with internal camera



(a) Lower cerebellum (b) Upper cerebellum

Fig. 4: Scenario 3 – Voyager with mobile camera (showing slices with example following a path up the brain stem)

IV. Discussion

For developing the BrainWatch VR software application, the Oculus Rift CV1 was selected in comparison with its competitors due to its availability as a device with companion runtime and software development kit. Various other VR systems were considered but were either not available or impractical at the time development began. For example, a CAVE style system [11] was not practical because the user cannot be expected to have access to or set up a complex projector array in a room. Unfortunately, the Open Source VR system appeared to be more of a test project with their HMD 2.0 version expected in the future. The PlayStation VR system arrived later to consumer production making it unavailable at the time, which left either Oculus Rift CV1 or HTC Vive as the two practical choices. Of these two, the Oculus Rift CV1 was chosen for the first version of our BrainWatch software based on a combination of existing and available code libraries as well as the device's specifications and cost. More recently, we have also begun development and testing with the HTC Vive VR system. Although not yet complete, it seems promising due to a number of open source libraries available for development. Unlike the HTC Vive and Oculus Rift, the PlayStation VR does not have open source libraries for software development, thus making development of BrainWatch for this device more difficult without applying for a special license from Sony. Moreover, at present, it appears that development with the Sony PlayStation VR requires use of the partner system, the Sony PlayStation 4 and other special peripherals. However, we expect users of our BrainWatch software to possess only a VR ready computer and VR headset device, without any other hardware such as a PlayStation 4 game console. For these reasons, we considered the PlayStation VR impractical.

BrainWatch VR software has been developed for the Oculus Rift VR system. In the future, AR systems may become more viable and prove to be more appropriate than VR systems for visualization of volumetric rendering of brain scans because of the potential problems and medical concerns caused by VR headsets. A type of motion sickness dubbed 'simulator sickness' can occur in some people when they visually see themselves moving in the simulation but do not feel themselves physically moving [12]. This VR problem does not occur in AR because AR does not visually isolate the user from the physical world experienced by the user. Instead, AR simply overlays a 3D image on the real physical world that surrounds the user. This different experience for AR allows the user to maintain a visual connection to the real world physically around them and thus experience movement both visually and physically, thereby reducing the chance for simulator sickness and the potential for confusion caused by lack of spatial awareness.

Future versions of our software will continue to improve upon our existing algorithms by including a built-in suite of 3D volume image processing tools for image denoising, isometric resizing, as well as re-orientation of the dataset when necessary for appropriate viewing. Other planned changes include updates to our current ray casting rendering algorithm to reduce image tearing due to dynamic and atypical volume clipping in relation to head movement. Alternative approaches for volume rendering algorithms are being explored within both MATLAB and Unity3D combining them with the Visualization Toolkit (VTK) [13]. Within VTK or MATLAB, smoothed trilinear and cubic interpolation are possibilities for providing a higher image resolution whether applied during preprocessing of data or rendering of the processed data. Filtering classes in these function libraries also allow for a variety of image denoising algorithms, including Gaussian smoothing and smoothing of polygonal isosurfaces. To revise our ray casting rendering algorithms, we intend to rebuild it from the ground up using a variety of code libraries and methods. We also plan eventually to pursue clinical research trials of the BrainWatch software for imaging dementias and neurodegenerative disorders.

V. Conclusion

Supported by recently available and affordable new hardware, we have developed software called BrainWatch for volume rendering of brain scans in a VR environment. In the future, the BrainWatch software package and available consumer devices for VR and AR will continue to improve, allowing users to better understand and explore the brain in a 3D virtual or augmented reality environment. The current version of BrainWatch for Oculus Rift will be available as a live demonstration at EMBC 2017 for attendees to experience the brain in VR.

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