A Multi-User Virtual Reality Application For Visualization And Analysis In Medical Imaging

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A MULTI-USER VIRTUAL REALITY APPLICATION FOR VISUALIZATION AND ANALYSIS IN MEDICAL IMAGING

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***Abstract*— 3D medical imaging provides an invaluable tool to the radiologist in visualizing normal and abnormal tissue and structure for the assessment of disease and treatment planning. Moreover, in difficult image disease assessment cases, as well as in the assessment of the early stages of the disease the need exists for a real time 3D collaborative platform. The objective of this paper was to develop a multi-user Virtual Reality (VR) application for visualization and analysis in medical imaging. The proposed platform is based on the Unity VR platform that is integrated with the very well-known and popular image Visualization Toolkit– VTK. The platform was evaluated successfully in the 3D visualization of images of the ADNI dataset. Future work will focus in integrating in the platform the visualization of quantitative imaging analytics as well as the evaluation of the platform in a more-wide spectrum of imaging cases.**

Keywords—medical imaging, virtual reality, data visualization, multi-users, patient centric.

I. INTRODUCTION

Nowadays, there are several imaging modalities such as Ultrasound (US), Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and X-RAY. However, the most efficient modality for soft tissue changes is MRI due to its higher spatial and tissue contrast resolution [1]. Pathology is mainly detected through 2D images, however in some cases such as tumors or serious fractures, only 3D imaging will provide information regarding the size and shape of the pathology which will prepare the surgeon before surgery.

Lately due to the modern technology scanners used and the improved rendering algorithms and resolution, there was an improvement in 3D imaging and reformat. These scanners offer hundreds of slices per study which is very inefficient for the radiologist. The possibility of having a 3D image as reference allows the radiologist to evaluate the entire anatomy in 3D views and then return back to standard 2D view for comparison and confirmation. Thus, 3D reconstruction is more frequently becoming a valuable technique to summarize in a concise and clear way the overwhelming number of slices produced by modern imaging modalities [2].

Apart from radiological diagnosis, 3D imaging is also used in the surgical planning especially of serious fractures that require operation therefore, 3D imaging through its life-like views will allow the surgeon to evaluate before surgery the seriousness of each case. Benefits include decreased exploratory during surgery and a lower risk of complications for the patient, all of which contribute to reduced surgical morbidity. Furthermore, 3D imaging is very useful in tumor evaluation as it will allow the radiologist to describe the tumor's location, angiogenesis and most importantly how it spreads in the surrounding tissue [3].

Technological advances in medical imaging, linked with the associate technological advances in -omics and electronic health records (EHR) analytics, context-awareness, and visualization, prescribe a new era, leading the way towards precision medicine [4], [5]. The wealth of today's healthcare big data, provide invaluable resources towards new knowledge discovery that has the potential to advance precision medicine [6].

In this context, the European Commission, published recently the European strategy for data [7] where it is envisioned that a common European health data space will be created, which is essential for advances in preventing, detecting and curing diseases as well as for informed, evidence-based decisions to improve the accessibility, effectiveness and sustainability of the healthcare systems. This will enable the offering of precision medicine patient centric services by better responding to the patients' needs by enabling doctors to take data-enabled decisions. Most importantly, it will make it possible to tailor the right therapeutic strategy to the needs of the right person at the right time, and/or to determine the predisposition to disease and/or to deliver timely and targeted prevention [7].

The above fast changing environment, necessitate the introduction of new intelligent EHR tools to support the health professional. Moreover, there is a need by the citizens for visualizing, maintaining and managing their own health data, even by enriching them through innovative applications[8].

The objective of this paper was to develop a multi-user Virtual Reality (VR) application for visualization and analysis in medical imaging in support mainly both the health professional as well as the patient. The proposed platform is based on the Unity VR platform that is integrated with the very well-known and popular image Visualization Toolkit– VTK. In section II, 'Toolsets Used' the paper documents the role of each application. In Section III, system requirements and specifications are covered as well as system development and implementation are documented. In Section IV, 'Results' the paper evaluates the application and in section V, 'Concluding Remarks' are given.

II. TOOLSETS USED

A. Virtual Reality - Unity Platform

Lopreiatio et al. [9] stated that VR simulations use a variety of immersive, highly visual, 3D characteristics to replicate real-life situations and/or health care procedures; VR simulations are distinguished from computer-based simulations in that they generally incorporate physical or other interfaces such as a computer keyboard, a mouse, speech and voice recognition, motion sensors, or haptic devices.

The user has the opportunity to "walk" in a virtual environment, explore different landscapes, turn his/her head or eyes at any time, travel in it, and interact with the objects around him/her. Both the perception of the environment and the user's interaction with it can be modeled based on reality. This virtual environment is already taking place in CT colonography which unlike traditional colonoscopy, which requires a scope to be inserted into the rectum, virtual colonoscopy uses hundreds of CT images to reconstruct and digitally manipulate a detailed view of the inside of the colon [10].

Virtual environments are directly connected to specialized material that provides complex interface systems and has new user interaction features. The virtual objects in it are projected onto the real world. This is done by using head-mounted screens that allow the user to see through them as well. Due to this level of activity, the user begins to feel that he is part of the virtual world, in a reality that he experiences in every detail.

VR offers an environment to facilitate the provision of medical care targeting in creativity and continuous testing to deliver effective systems, with pioneering technology, in the hands of the health professional. Furthermore, VR combined with virtual simulation solutions will allow clinicians to evaluate new interventional methods and procedures. Additionally, Computer-aided Detection (CAD) tools could be integrated into VR systems enabling the detection of abnormal tissue or organ function [11].

The users of the proposed imaging application will use the Oculus Quest to interact with it[12]. The Oculus Quest is the first all-in-one system created by Oculus VR for VR and users can interact almost anywhere with just VR headphones and controls. The device is completely autonomous, but can also be connected to the computer via a USB cable so that it can interact with applications that have not been transferred to it.

B. Visualization Toolkit - VTK

Visualization Toolkit (VTK) is an open source C ++ code library for 3D computer graphics, image processing and visualization[13]. It supports many visualization algorithms and modeling techniques. Applications that use VTK include Molekel, ParaView, VisIt, VisTrails, MOOSE, 3D Slicer, MayaVi and OsiriX. VTK is implemented for access via Python, Java and Tcl. It also implements OpenGL performance, which has been updated to OpenGL Core and can be used in external applications. This opens up the possibility of sharing OpenGL environments between VTK and Unity.

The Unity VR platform was integrated with the VTK toolkit in order to visualize 2D medical image data from an MRI examination as a 3D model in VR. The VTK integration into Unity facilitates the support of the VTK 3D volume visualization features as VR Unity scenery.

C. Image Processing and Analysis in Java - ImageJ

ImageJ is an image processing program based on the Java programming language and developed at the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation[14]. ImageJ was designed with an open architecture that provides scalability through Java plugins and registered macros. Customized acquisition, analysis and processing plugins can be developed using the built-in ImageJ processor and a Java compiler. ImageJ's plugin architecture and built-in development environment make it a popular image editing platform.

More specifically, the proposed imaging application used the ImageJ tool to convert an MRI scan to a set of 2D medical images. The executable file of ImageJ was integrated within Unity. System calls are executed within Unity, sending the necessary data (.hdr and .img files constituting the MRI data) to ImageJ so that it can be converted to .bmp files, which comprise the 2D medical images. Then .bmp files are used by Unity to create the 3D VR model.

III. SYSTEM DEVELOPMENT AND IMPLEMENTATION

Figure 1 illustrates the system analysis steps followed for the development of the proposed multi-user medical imaging VR platform.

In the requirements analysis step, the system functionalities were identified as given also in Fig. 1. The target here is to create a handy and reliable tool that will help the health professionals and the patients to visualize and interact. The tool supports the functionality either to be used by health professionals for teleconsultation or to be used by the health professional and the patient, so that the patient gains a better understanding of the underlying pathophysiology of his/her disease based on medical imaging.

The application should show the user the data of the 2D medical image from MRIs in a 3D VR model,

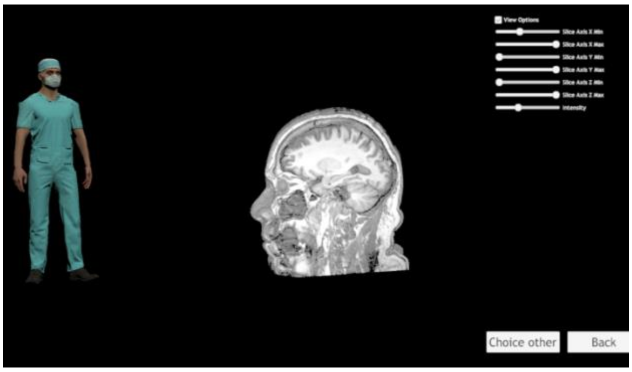

Figure 2: Visualization of MRI 2D medical image data in a 3D VR model.

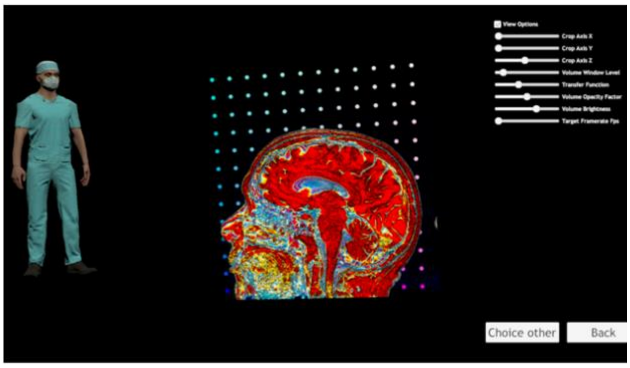

Figure 3: Visualization and processing of an MRI 3D VR model with the Visualization Toolkit.

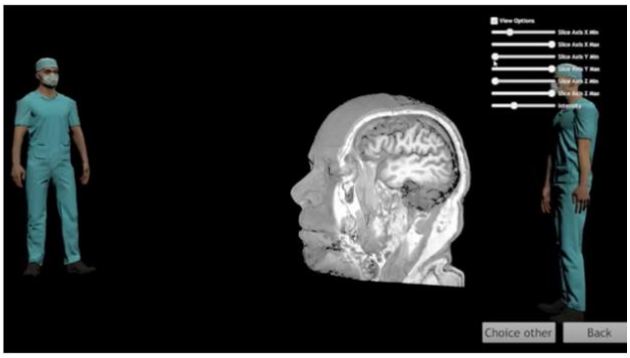

Figure 4: Multi – user virtual space access (of two health professionals, i.e. a Neuroradiologist and a Neurologist) and processing of an MRI3D VR model created from the 2D medical image data.

Figure 5: Visualization of 2D medical image data of left-hippocampus in an MRI 3D VR model.

achieve the interconnection of the VTK tool with the virtual environment, as well as enable the parallel access of users in the same virtual space.

The application accepts and processes medical images from MRIs, which are in the form of DICOM, HDR, MHD, SEQ.NRRD and NRRD. It creates and presents in the end the corresponding 3D medical model, which can be manipulated by the users. Furthermore, the interactivity functionality needs to be supported that enables the exchange of 3D model data between users who are simultaneously using the system.

The system design and use case scenarios followed the system requirements analysis. The following eight scenarios were developed as listed in Fig. 1:

1. Login to the system.
2. Selection of Medical Imaging.
3. Creation of an internet space for the possibility of multi-user access to the system.
4. File selection (MRI scan).
5. Selection of individual options when visualizing a 3D VR medical imaging model.
6. Selection of "Enable Match Maker (M)" button by the healthcare professional.
7. Finding an internet match space by the healthcare professional.
8. Participation in the internet space by the second healthcare professionals or the patient.

This step was followed by the system implementation, development and testing, and evaluation.

IV. RESULTS

A. System Evaluation

The functionality of the system was evaluated in detail by a medical imaging expert. The health professional considers that the application is innovative and useful both for the health professional and the patient, as it offers a unique way of interactivity facilitating constructive and effective communication.

B. Case Study Evaluation

The proposed platform was evaluated with MRI images downloaded from the ADNI database (http://adni.loni.usc.edu/). The ADNI was launched in 2003 by the National Institute on Aging, the National Institute of Biomedical Imaging and Bioengineering, the Food and Drug Administration, private pharmaceutical companies and non-profit organizations as a public-private partnership. The goal of the ADNI study is to determine biological biomarkers of AD through neuroimaging, genetics, neuropsychological tests and other measures in order to develop new treatments and monitor their effectiveness, and lessen the time of clinical trials.

Alzheimer's disease (AD) is a progressive neuro-degenerative disorder that develops in the brain and destroys its fundamental elements, the neurons. As a consequence, atrophy deteriorates in the brain and eventually the patient has difficulty in remembering recent events. MRI is a non- invasive imaging modality, which provides high spatial resolution images. Three Dimensional (3D) MRI images are used to estimate the structural changes initiate within the brain and detect the early signs of atrophy. Atrophy initially affects Medial Temporal Lobe (MTL) [15], [16] a region which includes anatomically related structures that are essential for declarative memory [17]. Within MTL, the neurodegeneration of hippocampus along with entorhinal cortex is linked to cognitive decline. From all the biomarkers used in the assessment of AD, hippocampal atrophy as assessed on high-resolution T1-weighted MRI represents the best established and validated biomarker [18]. Many studies have indicated that subjects who eventually converted to AD had more severe hippocampal atrophy compared to non-converters [19], [20].

Figures 2 to 5 illustrate the functionality of the system based on an MRI scan of an Alzheimer's patient. In Fig. 2, visualization of MRI 2D medical image data in a 3D VR model is shown, whereas in Fig. 3, visualization and processing of an MRI 3D VR model with the Visualization Toolkit is illustrated. Figure 4, illustrates the multi-user functionality of the system. In this figure, two healthcare professionals, a Neuroradiologist and a Neurologist are navigating in the same virtual space of an MRI 3D VR model created from 2D medical image data. The platform also supports the visualization of isolated structures extracted from the MRI scans. In Fig. 5 visualization of 2D medical image data of left-hippocampus in an MRI 3D VR model is illustrated. The hippocampus Regions of Interest (ROIs) were extracted off-line using the FreeSurfer Tool [21].

C. System Limitations

In the development of the multi-user access of the application, there was a synchronization issue in the integration of the VTK tool within the Unity tool towards generating/updating the 3D VR model in real time. In particular, the problem was in the exchanging of data between users who participated in the application at the same time. That is, there was a significant delay in the transmission and reception of large volumes of imaging data sets between the users due to the free version of the Unity tool that was used. To overcome this problem, the Unity tool was set up to record the screen buffer as texture2D. This is carried out by encoding a texture based string packaged for transmission. The exchange of data between the users is carried out based on this schema achieving close to real time visualization and navigation (with the time delay experienced usually to be a few seconds).

V. Concluding Remarks

Ongoing rapid advances in healthcare technology including medical imaging as well as in information and communication technologies prescribe an emerging new paradigm in the delivery of advanced healthcare services under the umbrella of the connected health paradigm [22]. In the context of this emerging connected health paradigm, this paper developed and implemented a multi-user VR application for visualization and analysis in medical imaging. The platform supports the functionality either to be used by health professionals for teleconsultation or to be used by the health professional and the patient, so that the patient gains a better understanding of the underlying pathophysiology of his/her disease based on medical imaging. The proposed platform is based on the Unity VR platform that is integrated with the very well-known and popular image Visualization Toolkit– VTK. The platform was evaluated successfully in the 3D visualization of images of the ADNI dataset.

To the best of our knowledge, a similar platform was also developed by Wheeler and coworkers [23]. Similarly to this paper, they proposed the integration of a Unity application that performs VTK volume rendering to display thoracic computed tomography and cardiac magnetic resonance images. It was shown that over 90 frames per second using standard hardware could be achieved, that is suitable for both VR and augmented reality applications. It is noted that in the application proposed in this paper, the exchange of data between the users achieved close to real time visualization and navigation, with the time delay experienced usually to be a few seconds based though on a free Unity version.

Future work will firstly focus in the evaluation of the platform in a more wide spectrum of imaging cases. Moreover, it is targeted to integrate in the platform the visualization of quantitative imaging analytics through the construction of imaging signatures (i.e., fusing shape, texture, morphology, intensity, etc., features) and their subsequent association to clinical outcomes [24].

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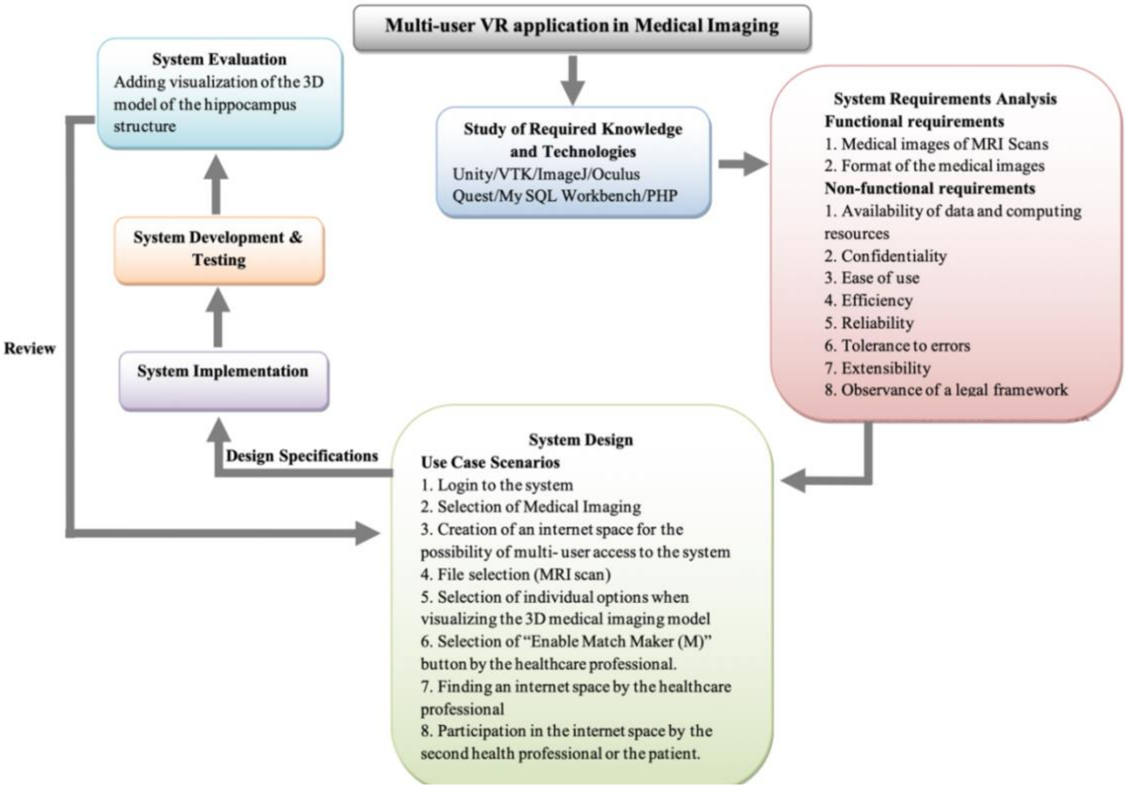

Figure 1: System analysis steps followed in the development of the multi-user VR medical imaging platform.