

Serious Game for Medical Imaging in Fully Immersive Virtual Reality

1st Hubert Cecotti
Department of Computer Science
Fresno State
Fresno, USA
hcecotti@csufresno.edu

2nd Michael Callaghan
Intelligent Systems Research Centre
Ulster University
Derry, Northern Ireland
mj.callaghan@ulster.ac.uk

3rd Benjamin Foucher
Polytech Nantes
Nantes, France
benjamin.foucher@etu.univ-nantes.fr

4th Stevens Joslain
Polytech Nantes
Nantes, France
stevens.joslain@etu.univ-nantes.fr

Abstract—Fully immersive virtual reality systems allow the implementation of new immersive user interfaces and data visualization applications that offer effective ways to interact with multidimensional neuroimaging data. Learning to interpret 3D medical imaging scans can be an intimidating experience for students given the large range of pathologies to visualize and the relative placement(s) and location(s) of areas of interest, a process which is further complicated by interacting with, manipulating, and navigating through images across several possible views. Gamification and Serious Games (SG) have proved to have instructional benefits for teaching and learning. The adoption and use of virtual reality in education is growing, driven by the availability of more powerful and affordable virtual reality (VR) headsets, allowing novel ways to interact with and explore teaching material. This paper explores the use of VR to teach the fundamentals of medical imaging interpretation and the opportunities available in using immersive 3D visualizations to understand the spatial relationships between parts of the body, key organs, and their constituent parts. An integrated immersive learning environment is presented that orientates and guides the student through this process and assesses their subsequent level of understanding. The use of gamification in this context to increase student engagement and retention is discussed.

Index Terms—virtual reality, medical imaging, neuroimaging, gamification

I. INTRODUCTION

Gamification has proved to have instructional potential and is increasingly used in an educational context to improve student engagement and retention [1]–[3]. Virtual reality (VR) is a situational computer-generated simulation, allowing users to be immersed in a task, abstracted from the real world, offering opportunities for experiential learning [4]. Interpreting medical imaging can be an intimidating experience for students, given the large range of pathologies to visualize, the relative placement(s) and location(s) of areas of interest and the further complication of interacting with, manipulating, and navigating through images across several possible views. Traditionally, learning the basic knowledge required for the

interpretation of medical imaging is done through two dimensional (2D) mediums while medical imaging, such as MRI scans, are 2D representations and slices of three-dimensional (3D) objects. This is a major drawback as the associated 3D spatial relationship(s) between parts of the body are obscured and to a greater extent lost within the constraints of a two-dimensional presentation layer. This paper explores the use of virtual reality to teach the fundamentals of medical imaging through image interpretation and the opportunities available in the use of immersive 3D spaces to understand and quantify the spatial relationships between key organs, location(s) and their constituent parts. This allows a closer view of the dissections, anatomical breakdowns and representations, in both two and three-dimensional spaces, which can be interacted with and manipulated inside a fully immersive virtual reality environment using the available controllers and peripherals to gain different perspectives and insights into the content and material. The game includes the use of leader boards and achievements to ensure a high level of user engagement, retention and simulation replay ability, through the inclusion of competitive elements. Players, such as students, must use and apply their knowledge and understanding of physical characteristics and spatial relationships between parts of the human body to successfully complete the game.

The remainder of the paper is organized as follows. Section II provides an overview data visualization for medical imaging. Section III discusses the design, implementation and functionality of an existing virtual reality system (Medical Imaging VR) for the upload, visualization and analysis of digital medical images. Section IV introduces an extension to the project, which includes additional features and functionality along with a game-based element to teach users how to read an MRI scan, identify and locate brain and body parts and explain their function(s) while understanding the different two-dimensional view types alongside three-dimensional 3D visualization functionality. Section IV presents the practical implementation of the virtual reality environment developed. Section V presents the conclusion and future work in this area.

II. MEDICAL IMAGING DATA VISUALIZATION

Medical imaging techniques allow the creation of pictures of the anatomy. Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) scans produce detailed images of anatomical parts (e.g. brain, heart) with a view to helping clinicians and researchers. Magnetic resonance imaging (MRI) is a non-invasive scanning procedure using strong magnetic fields and radio waves to produce detailed images of regions and organs inside the body, which can then be used to aid the diagnosis and monitoring of a wide variety of medical conditions. The segmentation and detection of tumors can be performed through the visualization of MRI scans and medical imaging techniques [5], [6]. 3D models created with MRI pictures appeared in the late 90s [7]. Such a medical imaging technique allows scientists to handle a volume of an analyzed body part. They can visualize an object from different points of view. Anatomical structures can be highlighted or isolated with a colorization algorithm, which provides a better view of the regions of interest. MRI data is in 3D. It is challenging to adequately display 3D data and all the corresponding slices in 3D on a 2D computer screen. A computerized tomography scan (CT or CAT scan) uses computers and rotating X-ray machines to create cross-sectional images of the body. These images provide more detailed information than normal X-ray images. Many software packages provide tools for digital image processing, analysis, and visualization (e.g., 3DSlicer [8]). The creation of figures including perspective and that can convey 3D information, such as depth, is a possible solution to this problem. Such processing step can be performed through standard functional MRI analysis packages (e.g., 3DSlicer, AFNI, FreeSurfer, Mango, MRICroGL, and SPM).

3D data visualization can be beneficial for multiple groups of individuals. First for educational purposes, students in medical school or cognitive neuroscience can use visualization tools for having a better understanding of the relationships between regions with an organ (e.g., the brain). Students can display and browse across different brain regions. Second, neuroscientists can analyze data from different points of view to obtain new knowledge and help in data selection and analysis techniques. With the emergence of big data analytics, effective data visualization is an essential element of learning, research methodology, and the discovery process. It is the connection between the quantitative data content and human intuition and intelligence. It is a key stage of the journey towards discovery from data into knowledge and understanding. In addition, visualization is fundamental in the data mining process, driving algorithms selection, from the denoising and pre-processing techniques to the segmentation, in helping to identify and remove outliers from the analysis. Third, patients who wish to understand what is happening in their head, in the case of a brain MRI, can benefit from such a visualization. For instance, assessing the evolution of a tumor through relevant visualization tools can help the clinicians for establishing the diagnosis, and for the patient to learn and understand the situation. The 2D or 3D representation of a body part scan

can be observed at its true size, e.g., to visualize the size of the different structures in the brain or by enlarging the size of the brain to show and enhance all the details. An MRI scan may give highly sensitive details of brain, spinal cord, and vascular anatomy thanks to its spatial resolution.

A 3D medical imaging scan is represented by a series of slices in the 3 anatomical planes. These three planes are used for describing the location of regions and organs in the human and animal anatomy. The sagittal plane (y - z) divides the body into left and right; its other names are the median, longitudinal, or anteroposterior plane. This plane is parallel to the sagittal suture. The coronal plane (x - y) divides the body into dorsal and ventral (back and front, or posterior and anterior) portions; its other names are the frontal or vertical plane. The transverse plane (x - z) divides the body into cranial and caudal (head and tail) portions; its other names are the axial, lateral, or horizontal plane.

For a visualization in 2D, the 3 displayed panels correspond to a plane; a location at the coordinate (x, y, z) will be displayed on each panel. Changing the coordinates in one panel has a direct effect on the other two views depending on the shift in the x , y , or z directions. This representation of the volume with multiple views can be challenging for an inexperienced user, making difficult to grasp the 3D aspect of the entire set of images in each plane. Despite all the possible ways to display 3D information on a 2D space in a static way (images) or dynamically with animations, the most natural way is the analysis of a 3D volume within a 3D environment that can occur now in a virtual environment.

III. MEDICAL IMAGING VIRTUAL REALITY

Immersive virtual reality environments can provide a better understanding for the analysis of multi-dimensional data in different scientific fields. Recent studies have shown the impact of immersion for the better understanding of data, e.g., brain tumors [9], shape perception [10], and MRI [11]. Moreover, VR can be combined with machine learning for the classification of hand drawn symbols in 3D [12]. This research has shown that data visualization provides some substantial help in the analysis of multi-dimensional data. Volume visualization is one of the most important areas in scientific data visualization [13]. The design and a prototype implementation of a 3D visualization system was proposed to assist with laparoscopic surgical procedures [14]. Virtual reality is used for the visualization and interaction with 3D graphs [15]. They implemented a software with the Unreal Engine version 4 with an emphasis on the design, increasing the usability of the application. Fully immersive virtual reality interface could provide enhanced views leading to a better understanding as human beings have an inherent ability to understand representations of objects in 3D space rather than 2D space [16]. However, the advantages of 3D space representations for information visualization tasks remain a research question [17], [18].

Medical Imaging VR is an immersive, virtual reality application, available on the STEAM gaming platform and

created using the Unity games engine, which allows users to upload, view, browse, and interact with magnetic resonance imaging scans (MRI), identifying, exploring, analyzing and visualizing parts of the body. The environment created includes two main elements, a cube that displays the MRI scan in three-dimensions and three panels with the conventional two dimensional Sagittal (y-z plane), Coronal (x-y plane), and Transaxial (x-z plane) anatomical views (see Fig. 1). The three-dimensional cube visualization is reconstructed in the immersive environment by combining individual DICOM (Digital Imaging and Communication in Medicine) files from an MRI scan, where DICOM is the specification for the creation, transmission, and storage of digital medical images and report data [19], [20].

The user can browse existing content or upload their own scans for viewing and manipulation, navigating through the slices using the slider(s) on each axis and the virtual reality controllers. The environment is highly functional allowing the user to rotate the cube, add and move a clipping plane to render different views, change transparency, threshold, and contrast, and use a range of color transfer functions to customize and tailor the visualizations. This software could be used for educational purposes as a learning tool for formative assessment, and by neuroscience researchers for browsing through medical imaging 3D scans.

Each voxel of the 3D medical imaging data has to be mapped into an RGBA value (Red, Green Blue, Alpha: transparency of the object). The volume consists of the 3D rendering of the data. Contrast and threshold can be adjusted, and the colorization can be tuned or disabled. The clipping plane determines the limit of the object rendering, and it is represented by a yellow square. The orientation of the volume can be changed by the user through buttons to allow a view of the 3D data with the desired vantage point. Furthermore, the direction of the clipping plane can be toggled by the user. With the 3D rendering, the user can visualize the regular 2D views of the 3D data, in the three anatomical planes: Sagittal (y-z plane), Coronal (x-y plane), and Transaxial (x-z plane) (see Fig. 2. The user can browse through the slices with the slider on each axis with buttons (see Fig. 1).

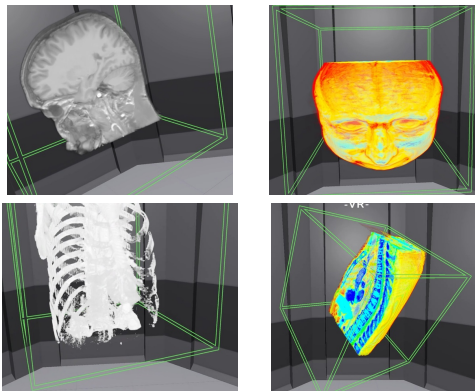


Fig. 1. Representative examples of views.

IV. MEDICAL IMAGING INTERPRETATION

Teaching students to interpret 3D scans can be challenging given the inherent interdisciplinary nature of the topic, the expense and complexity of many types of cognitive neuroscience technologies and the need to have an appropriate multi-disciplinary knowledge foundation. The focus of this project is to extend the existing Medical Imaging VR environment to add additional features and functionality to teach users how to read a medical imaging scan, identify and locate main brain and body parts and explain their function(s) while understanding the different two-dimensional view types alongside three-dimensional 3D visualization functionality. For project planning and implementation, the ASSURE instructional design model was used [21], [22]. The main teaching material developed broadly aligns with elements of the key stage 4 higher Biology curriculum taught as part of the General Certificate of Secondary Education (GCSE) in the UK where the target end user would be between 14 and 16 years of age but would be of interest and useful to a wider demographic. A learner-centered strategy was employed with gamification features, a quiz and competitive elements included to increase user engagement, retention and simulation replay ability, where users must demonstrate and interactively apply their knowledge and understanding of the physical characteristics, location(s) and spatial relationships between parts of the human body to earn badges, achievements and hold a high rank on a leader board.

Successful completion of the gamification and quiz element(s) validates the approach taken, demonstrating that users have met the following learning outcomes:

- Understand the fundamentals of how to read a 3D scan of the head
- Understand the difference(s) between axial, sagittal, and coronal views
- Learn about the anatomy of the head, the different parts of the brain, associated body parts and their function(s) and how to identify and locate key regions and features of interest

The menu of the title scene is presented in Fig. 3. It includes a tutorial scene explaining the different views and plane types, a guided interactive tour, which identifies the main physical features of the brain, their location(s) and general relative proximity with related description of their main function(s) and quick start location functionality where the user can select an area of interest from a menu system, which is then loaded on the 2D view panels, and its location highlighted in the 3D cube with the main functionality of that element described. Finally, a quiz and assessment area was created where users can test their knowledge and understanding of the subject material, through correctly answering questions, by physically navigating through the 2D panels and 3D cube using the controls provided, to directly locate the correct area or identify it based on a description of its function. This element is competitive with users ranked in STEAM leader boards. Navigation and guided use of each of these sections is facilitated by a voice driven narrator with accompanying

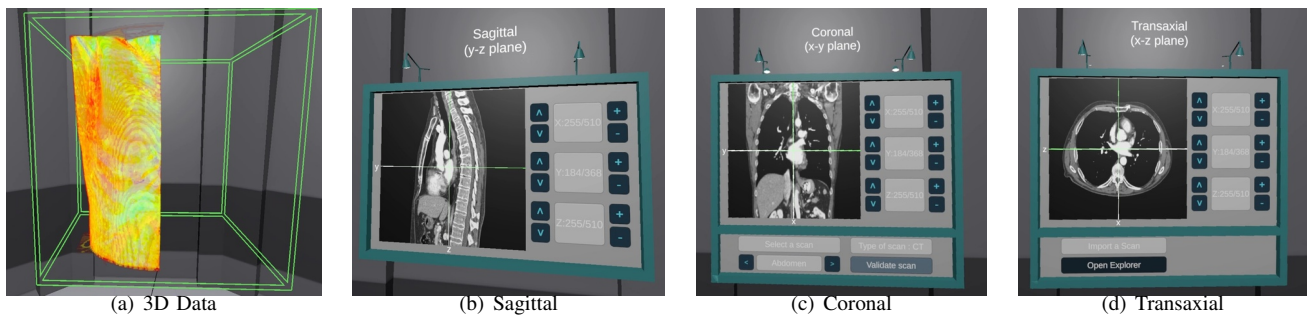


Fig. 2. Virtual reality scene with (a): the 3D data, (b): the sagittal (y-z), (c): coronal (x-y), (d): transaxial (x-z) planes.

text explanations. Successful completion will earn the user related and graduated achievements. Each of these areas are now discussed in more detail.

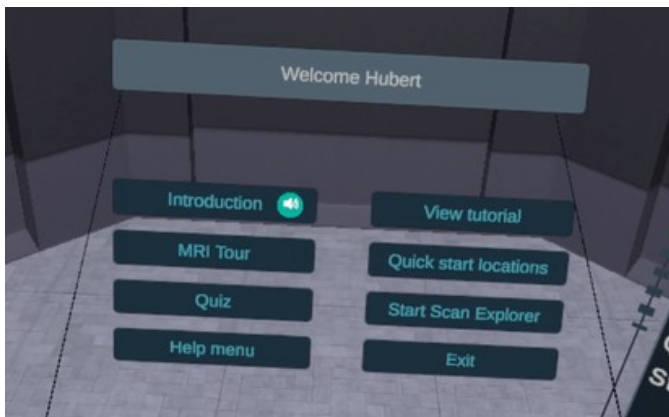


Fig. 3. Scenes with navigation in orientation area.

A. Tutorial

The human body is a three-dimensional structure where any location or anatomical view can be localized using X, Y and Z coordinates, related axes and planes i.e., sagittal (y-z plane), coronal (x-y plane), and transaxial (x-z plane). In the View tutorial, the player is introduced to these views and planes individually and their practical use when exploring or navigating scans of the body through an interactive, narrated tutorial. The corresponding view for each plane is simultaneously shown on the 3D cube (Fig. 4).

B. Tour of the brain and related areas

In this scene the user is guided through an interactive, structured and narrated tour of major areas of the brain and head, their location(s), general proximity and main functions and roles. Over 55 regions are identified, displayed and localized in the axial, sagittal and coronal views using crosshairs and an ellipsoid. Corresponding descriptive audio with text is shown below with the panel giving the best view of that area indicated using a color-coded system. The region is also highlighted in the 3D cube view (which can be rotated), to improve overall physical and spatial awareness e.g., relative

size, physical characteristics, location and orientation (Figure 4). The ellipsoid can be toggled on and off for clarity. All the regions are defined in a JSON file (code 1) so an instructor can easily modify their content, it contains the coordinates of position and the radius of the ellipsoid.

Listing 1. Example of region.

```
{
  "id": 7,
  "namePart": "Sella turcica",
  "descriptionPart": "The Sella Turcica is ...."
  ,
  "positionPartX": 90,
  "positionPartY": 201,
  "positionPartZ": 267,
  "radiusX": 16,
  "radiusY": 20,
  "radiusZ": 24,
  "bestView": "Sagittal"
}
```

C. Quick start locations

In this area, the users are presented with two menus located to the left and right of the 3D cube with an additional selection and navigation menu added to the information panel below the view panels (Fig. 5). From these menus, the user can select and directly access the area of the brain or body part of interest. This location is loaded into the view panels and 3D cube and highlighted as before with additional supporting, descriptive material provided by audio and text.

D. Quiz and assessment area

In the quiz and assessment area, the users can test and assess their understanding of the subject material through a gamified quiz. The quiz is time based where the objective is to answer all the questions correctly in the shortest possible time to get a high score, earn achievements and secure a place on the leader board. There are 15 questions to answer for each quiz session based on three question types randomly selected from a bank of 60 questions. For question type 1 and 2, a correct answer is achieved by physically locating and navigating to the required area using the controls available on the panels. This requires the student to have a good understanding of brain anatomy, associated body parts, geographical, physical, and relative locations and which view to use to navigate there in the shortest possible time. For each question type, there is a



Fig. 4. Tutorial scene.



Fig. 5. Locations of the different parts in the head scan.

hint option available that uses a graduated color scale (from red to green) in the sagittal, transaxial, and coronal planes to represent the distance from/to the target region, where green is the correct value for that plane and red indicates that the location is some distance away. Each time a hint is used a time penalty is incurred (Fig. 7). The hints decrease the difficulty level and allow users to explore and search the regions using a “hot and cold” type of gameplay.

For question type 1, the user must identify, locate, and navigate to a specific location of the brain or head using the navigation and selection tools provided on the 2D and 3D panels based on a description of that area or its function. When they have located the required area, they must press the validate button on the quiz panel to confirm their choice and receive feedback before proceeding.

Question type 2 is multiple choice where a description or function of an area is provided along with four possible options with one correct answer to choose from. When an option is selected and validated the correct answer is highlighted and feedback given (Fig. 6). When the quiz is complete, feedback is given on the number of correct answers, the overall score, time taken and if warranted achievements earned and place on the leader board.

The questions are also stored in a JSON file (code 2). The questions include an identifier (id), the type of question, the title of the question, and the answer. For questions with multiple choices, the alternative wrong choices are automatically selected.

Listing 2. Example of region.

```
{
  "id": 32,
  "typeQuestion": 0,
  "question": "Locate the Hypothalamus",
```

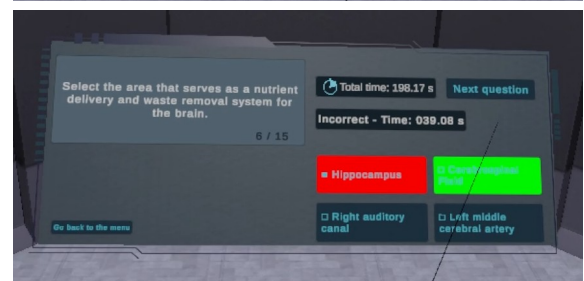
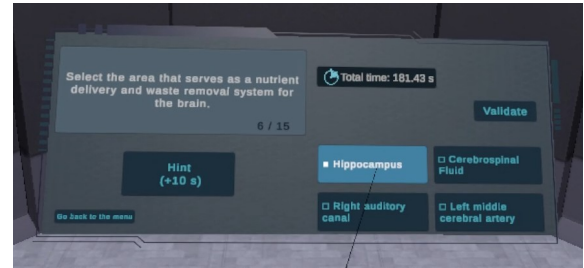


Fig. 6. Question with multiple choices (top: question; bottom: feedback).

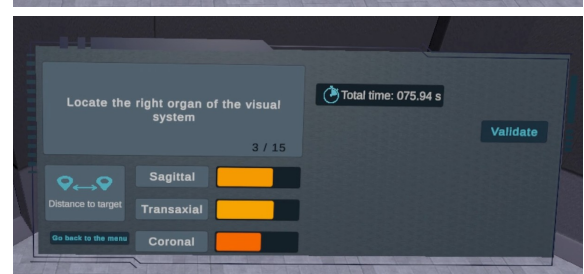
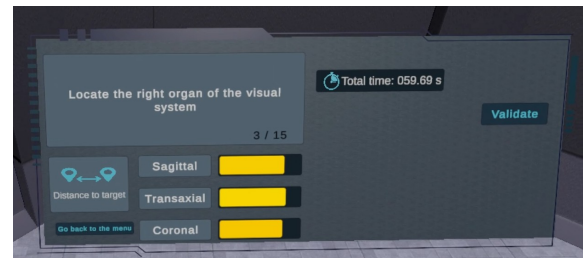


Fig. 7. Hint given to the user based on the distance between the center of the target region and the current position.

```
  "brainPart": "Hypothalamus"
},
{
  "id": 33,
  "typeQuestion": 1,
  "question": "Select the area of the brain
```

Name	Type	# Coronal	# Sagittal	# Transaxial
Abdomen	CT	511	511	369
Arm	CT	453	511	219
Brain	MRI	512	181	512
Cardiac	MRI	30	192	44
Foetus	MRI	58	23	40
Knee	MRI	20	22	24

TABLE I
DATA FOR TESTING.

```

    that regulates body temperature",
    "brainPart": "Hypothalamus"
}

```

E. Scan explorer

The system allows to browse among different types of medical imaging scans, including both MRI and CT scans. The list of scans is given in Table I. In addition, users can add data directly in the application by creating folders with images corresponding to the three views. The interface provides an option to import such folders.

F. User Interface

The input modalities for the Valve Index, HTC Vive, and Oculus Quest controllers are represented in Fig. 8. All the controls are based on a single action that is performed with the trigger of the controller. This simple approach allows users who do not have any experience with VR controllers or video games to properly use the application. The rotation of the cube that containing the 3D scan is performed through the trackpad in each controller. By using the touchpad, i.e., there is no click for rotating the cube. The parameters of the view (e.g., visualization in color or in graylevel, a threshold to adapt the level of transparency) are accessible through buttons below the cube. The clipping plane can be set in one of the three directions. At a given slice corresponding to the clipping plane, one side of the cube represents the volume cut at the selected slice, and the rest of the volume is transparent. The view can be toggled, i.e., the part of the cube that was transparent becomes visible, the visible part becomes transparent. The panel of the user interface is presented in Fig. 9. In each panel, it is possible to browse among the slices with two speeds: it is possible to navigate across the slices one by one, or by letting the trigger pressed to move across multiple slices. These two options are offered so the user can be both precise for the selection of a desired slice, and fast by browsing multiple slices without pressing the trigger multiple times.

G. Implementation

The Unity game engine was used for the application development. The SteamVR plugin was used to allow different VR headsets to be used. This plugin gives tools for dealing with input modalities (e.g., touching, grabbing, and using objects), giving the player to control buttons and sliders with a laser pointer. This provides the functionality to teleport in the VR scene by pointing to an area with the controller. The evaluation was performed on a desktop with an i7-6700K 4.00 Ghz, 32GB

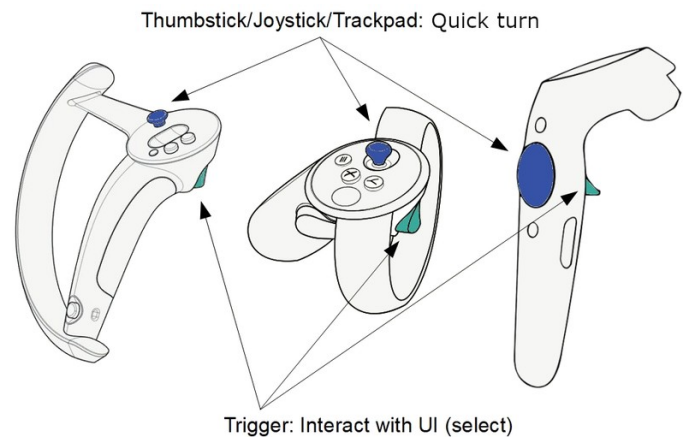


Fig. 8. Controls for the user interface and locomotion (**left**: Valve Index, **middle**: Oculus Touch, **right**: HTC Vive).

Ram, Nvidia Geforce GTX 1080, Windows 10 Enterprise 64 bit. The software has been deployed on the Steam platform and it can be downloaded at this address [23]: <https://store.steampowered.com/app/1471980/MedicalImagingVR/>.

V. DISCUSSION AND CONCLUSION

In this paper, we have proposed a new fully immersive virtual reality application for learning about medical imaging and how to navigate within a 3D medical scan, using medical imaging data, such as MRI and CT scans. As the application reads set of images, it can be used for any 3D data, going beyond medical imaging. The 3D data can be accessed within a scene with two possible views: a 3D volume, and three 2D planes. The system described in this paper has two main purposes. Firstly, it can be an immersive learning tool for teaching neuroanatomy to students. Secondly, it can be a data visualization tool in biomedical and neural engineering, where signal visualization plays a substantial role in the ability of researchers in neuroscience to retrieve and analyze information. Data visualization complements data analysis for better exploration of and acquiring new knowledge from data that is in a high dimensional space. A common advice given to students in science starting out is to first look at the data (images or signals) before starting anything, e.g., classification, segmentation, etc. Moving from a 3D representation on a 2D screen to a 3D VR environment is not a seamless process with some challenges. The graphical aspect for the representation of the 3D elements in the VR environment has some technical constraints related to number of slices that impacts the frame-rate. A key aspect to be taken into account is the usability and the user experience, how a person without experience in a VR environment can properly navigate, select, and manipulate objects. The design and development in VR requires careful attention to the human computer interaction aspects, how the objects in the scene are presented and how it is possible to interact with them.

This freely accessible fully immersive virtual reality educational software can be used for multiple purposes: for

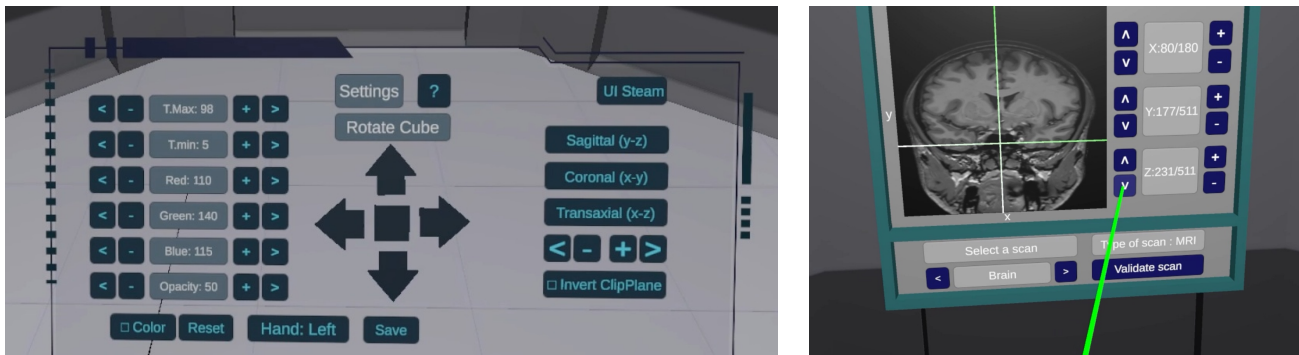


Fig. 9. Panel with the buttons for changing the color scheme of the 3D volume and selecting the view. The user can change the transparency and the colormap of the cube by modifying the RGB component. The user can determine some thresholds to limit the data visualization to only some colors.

displaying 3D medical imaging data for researchers, clinicians, and students in medical school and is accessible and flexible enough to be used by younger students studying biology. The application includes multiple views for the effective visualization of the 3D data: the classical view typically represented on 2D screens with 3 panels that represent the sagittal, coronal, and transversal planes; and the 3D representation within a volume that provides a direct access to slices from different vantage points. These two modes of visualization are related: selecting a slice in a view will modify the views of the volume, and vice versa. Future work will include the automatic extraction of the slices from DICOM files directly through the VR application, for loading DICOM files within the VR environment. Because the number of slices can largely vary in relation to the resolution, it will be necessary to provide interpolated slices to enhance the user experience.

Acknowledgments

The authors would like to thank Alan Billant, Alan Lerdung, Lucas Nicod, Hugo Richard, and Quentin Richard for their contributions.

REFERENCES

- [1] M. Prensky, "Information and background on the monkey wrench conspiracy," <http://www.marcprensky.com/>, accessed: 2021-08-01.
- [2] E.-S. Aziz, S. K. Esche, and C. Chassapis, "Review of the state of the art in virtual learning environments," *Computers in Education Journal*, vol. 20, no. 1, pp. 22–35, 2010.
- [3] Z. Kosmadoudi, T. Lim, J. Ritchie, S. Louchart, Y. Liu, and R. Sung, "Engineering design using game-enhanced CAD: The potential to augment the user experience with game elements," *Computer-Aided Design*, vol. 45, no. 3, pp. 777–795, 2013.
- [4] C. Flavian, S. Ibáñez Sánchez, and C. Orús, "The impact of virtual, augmented and mixed reality technologies on the customer experience," *Journal of Business Research*, vol. 100, pp. 547–560, July 2019.
- [5] M. A. Balafar, A. R. Ramli, M. I. Saripan, and S. Mashohor, "Review of brain mri image segmentation methods," *Artificial Intelligence Review*, vol. 33, pp. 261–274, Mar. 2010.
- [6] N. Gordillo, E. Montseny, and P. Sobrevilla, "State of the art survey on mri brain tumor segmentation," *Magnetic Resonance Imaging*, vol. 31, pp. 1426–1438, Oct. 2013.
- [7] M. Bomans, K.-H. Höhne, G. Laub, A. Pommert, and U. Tiede, "Improvement of 3D acquisition and visualization in MRI," *Magnetic Resonance Imaging*, vol. 9, pp. 597–609, 1991.
- [8] S. Pieper, M. Halle, and R. Kikinis, "3d slicer," in *Proc. of the 1st IEEE Int. Symposium on Biomedical Imaging: From Nano to Macro*, vol. 1, 2004, pp. 632–635.
- [9] S. Zhang, C. Demiralp, D. F. Keefe, M. DaSilva, D. H. Laidlaw, B. D. Greenberg, P. J. Basser, C. Pierpaoli, E. A. Chiocca, and T. S. Deisboeck, "An immersive virtual environment for DT-MRI volume visualization applications: A case study," in *Proc. of IEEE Visualization*, 2001, pp. 437–584.
- [10] C. Demiralp, C. D. Jackson, D. B. Karelitz, S. Zhang, and D. H. Laidlaw, "CAVE and fishtank virtual-reality displays: A qualitative and quantitative comparison," *IEEE Trans. on Visualization and Computer Graphics*, vol. 12, pp. 323–330, 2006.
- [11] J. Chen, H. Cai, A. P. Auchus, and D. H. Laidlaw, "Effects of stereo and screen size on the legibility of three-dimensional streamtube visualization," *IEEE Trans. on Visualization and Computer Graphics*, vol. 18, pp. 2130–2139, 2012.
- [12] H. Cecotti, C. Boumedine, and M. Callaghan, "Hand-drawn symbol recognition in immersive virtual reality using deep extreme learning machines," in *Int. Conf. on Recent Trends in Image Processing and Pattern Recognition (RTIP2R'16)*, 2016, pp. 80–92.
- [13] T. T. Elvins, "A survey of algorithms for volume visualization," *ACM SIGGRAPH Computer Graphics*, vol. 26, pp. 194–201, Aug. 1992.
- [14] H. Fuchs, M. A. Livingston, R. Raskar, D. Colucci, K. Keller, A. State, and J. R. Crawford, "Augmented reality visualization for laparoscopic surgery," in *Proc. Int. Conf. on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, 1998, pp. 934–943.
- [15] U. Erra, D. Malandrino, and L. Pepe, "Virtual reality interfaces for interacting with three-dimensional graphs," *International Journal of Human-Computer Interaction*, vol. 35, no. 1, pp. 75–88, 2019.
- [16] U. Erra, G. Scanniello, and N. Capece, "Visualizing the evolution of software systems using the forest metaphor," in *Proc. 16th Int. Conf. on Information Visualisation*, 2012, pp. 87–92.
- [17] R. Brath, "3d infovis is here to stay: Deal with it," in *IEEE VIS International Workshop on 3DVis*, 2014, pp. 25–31.
- [18] J. P. McIntire and K. K. Liggett, "The (possible) utility of stereoscopic 3d displays for information visualization: The good, the bad, and the ugly," in *Proc. IEEE VIS International Workshop on 3DVis (3DVis)*, 2014, pp. 1–9.
- [19] W. Bidgood, S. C. Horii, F. W. Prior, and D. E. Van Syckle, "Understanding and using DICOM, the data interchange standard for biomedical imaging," *Journal of the American Medical Informatics Association*, vol. 4, pp. 199–212, 1997.
- [20] P. Mildnerberger, M. Eichelberg, and E. Martin, "Introduction to the DICOM standard," *European Radiology*, vol. 12, pp. 920–927, 2002.
- [21] S. Kurt, "ASSURE: Instructional design model," *Educational Technology*, Nov 2015.
- [22] B. Sezer, F. Karaoglan Yilmaz, and R. Yilmaz, "Integrating technology into classroom: The learner-centered instructional design," *International Journal on New Trends in Education & Their Implications (IJONTE)*, vol. 4, no. 4, pp. 134–144, 2013.
- [23] X. XXXXX, "Medical imaging VR," 2020. [Online]. Available: <https://store.steampowered.com/app/1471980/MedicalImagingVR/>