

Rendering and interacting with volume models in immersive environments

Joan Fons¹, Eva Monclús¹, Pere-Pau Vázquez¹, Isabel Navazo¹

¹ViRVIG Group, UPC-BarcelonaTech, Barcelona

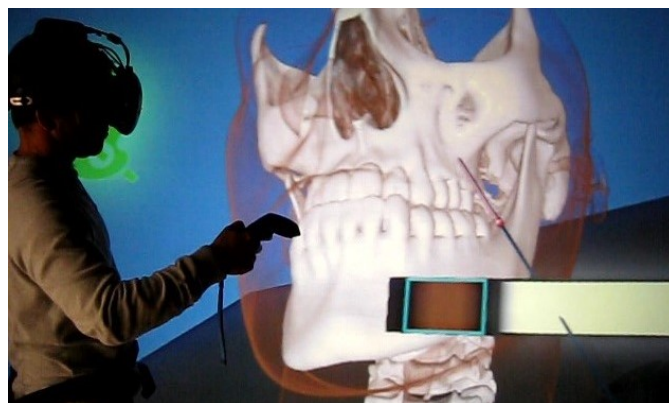


Figure 1: Overview of the system: The user is changing interactively the transfer function used in the volume model rendering. The image on the back shows what the user is seeing with the head mounted display.

Abstract

The recent advances in VR headsets, such as the Oculus Rift or HTC Vive, at affordable prices offering a high resolution display, has empowered the development of immersive VR applications. In this paper we propose an immersive VR system that uses some well-known acceleration algorithms to achieve real-time rendering of volumetric datasets in an immersive VR system. Moreover, we have incorporated different basic interaction techniques to facilitate the inspection of the volume dataset. The interaction has been designed to be as natural as possible in order to achieve the most comfortable, user-friendly virtual experience. We have conducted an informal user study to evaluate the user preferences. Our evaluation shows that our application is perceived usable, easy to learn and very effective in terms of the high level of immersion achieved.

CCS Concepts

•Computing methodologies → Computer graphics; Virtual reality; Volumetric models;

1. Introduction

Virtual Reality (VR) technology offers several advantages for scientific visualization, among them, the ability to perceive 3D data structures in a natural way. The recent advances in VR headsets, such as the Oculus Rift or HTC Vive, at affordable prices offering a high resolution display, has empowered the development of VR applications using this kind of immersive systems [LJKM*17]. In medicine, the visualization of 3D medical images plays a critical role in diagnosis and therapy [PB13, TREO16]. The use of VR in

medicine has been demonstrated to be very effective in terms of a better comprehension of the 3D volume datasets [LSSB12]. However, in order to facilitate its integration in the clinical practice, these applications have to be effective in terms of performance and accuracy, easy to learn and use with a friendly and intuitive user interface, and minimizing the data preprocessing required. In parallel, the development of Unity 3D [Uni18] (a friendly development framework) that facilitates the integration of different VR devices and the implementation of new 3D interaction techniques, has reduced the development effort that VR applications used to have in

the past. Unfortunately, the Unity platform was designed for rendering and managing surface models, as a consequence, when it is used for rendering 3D volume models does not yield interactive framerates and several acceleration strategies have to be implemented to achieve real-time rendering.

Thus, our goal is the development of a framework for the visualization of medical images (volume datasets) using the state of the art technique, GPU-based raycasting [HKRS*06] on head mounted displays (HDM). We use as reference for our implementation the HTC Vive system. Moreover, since HTC-Vive setup requires about 90 frames per second to allow comfortable movements in the virtual scenario without getting sick, we have implemented some speed-up techniques in order to increase the performance of our initial implementation. Moreover, we have incorporated different basic interaction techniques to facilitate the inspection of the volume dataset. The interaction has been designed to be as natural as possible in order to achieve the most comfortable, user-friendly virtual experience. We have conducted an informal user study to evaluate the user preferences. Our evaluation shows that our application is perceived usable, easy of learn and very effective in terms of the high level of immersion achieved.

2. Related work

Some techniques have addressed the creation of tools for the interaction with volumetric models in semi-immersive VR environments. Hinckley *et al.* [HPGK94] proposed a 3D user interface for pre-operative neurosurgical planning based on the physical manipulation of familiar real-world objects (head, cutting-plane and stylus-shaped props) in free space to access and manipulate a virtual model. Preim *et al.* [PTSP02] and Rossling *et al.* [RCD*10] propose a set of tools for measurements of distances, angles, or volumes in VR setups, although working with triangle-based models. Reitinger *et al.* [RSBB06] also presented a 3D measurement toolkit developed for liver surgery with triangle-based models. Their evaluation indicated that VR-based measurement tools have a sufficient benefit compared to 2D desktop-based systems in terms of task completion time. In terms of accuracy, slightly better results in most of the tasks were achieved. Another work also tailored to perform measurements in VR setup is due to Monclús *et al.* [MVN13], where a new, data-guided interaction metaphor is proposed for the efficient and accurate anchor point selection in volume models. Coffey *et al.* [CML*12] propose a technique for exploring volumetric models using the World in Miniature metaphor by the use of a multitouch surface and a stereo wall. Monclús *et al.* [MDNV09] developed a pointing technique tailored to facilitate volumetric data inspection with the simultaneous use of two different transfer functions. More recently, Preim *et al.* [SPP17] adapt their previous work presented in [PTSP02] to an immersive VR setup, such as an Oculus Rift DK2. In this paper, we analyse the use of immersive VR to medical volume datasets by adapting previous semi-immersive interaction techniques.

3. Overview of the system

Our immersive VR setup comprises a HMD *HTC Vive* used as output device and we handle the input with two *HTC Vive* controllers (see Figure 1). The application is developed using *Unity 3D*.

As commented above, the 3D volume model is rendered using a Direct Volume Rendering (DVR) approach such as a GPU-raycasting pipeline [HKRS*06]. The *HTC Vive* has a resolution of 1080x1200 pixels per eye with a fresh rate 90Hz (45Hz per eye), these requirements makes mandatory the use of optimization algorithms in order to make the system feasible. We have introduced two improvements into the basic raycasting pipeline: First, we use a reduced viewport and scale up the resulting image using interpolation. Since GPU-based raycasting is a screen-space algorithm, this is a simple but effective recipe for cost reduction. A second stage where there is room for improvement, is the number of texture accesses, which limits the algorithm speed. Thus, we substitute the computation of gradients, usually done on the fly (which require 6 extra texture fetches) for a pre-calculated dataset. This is a clear case where we trade computation for memory, but the capabilities of the *HTC Vive* make this advantageous for us. So, Gradients are stored as a 3D RGBA texture (gradient direction and its magnitude). Complementary, we have included an empty-space-skipping technique in order to avoid sampling the ray in completely transparent sub-volumes [PB13].

Apart from the volume dataset rendering, the VR environment shows a 3D panel with all the functionalities developed. The left *HTC Vive* controller manages its 3D location and its interaction. The right *HTC Vive* controller is in charge of all the interaction with the volume dataset. Because the interaction with the volume dataset follows the raycasting paradigm [LBLE15] we enhance the visualization of the *HTC Vive* controllers with a pointing ray.

4. Interaction metaphors

The inspection of a scene in a head-mounted VR setup is usually carried out by real user movements around the model as you would do in a real scenario. This is a very intuitive and natural way of exploring a 3D scene but for the specific inspection of a volume dataset, it could be insufficient. For instance, in order to understand the high complexity of some volume datasets, it could be interesting to add some way of clipping the volume model to reveal its interior and therefore only render a slab of the volume dataset. Also, providing some mechanism to change the position and orientation of the volume model without having to change the user position is very useful. The modification of the transfer function (TF) is also a task that usually requires accurate interaction. To provide a better user experience, we have created a new interaction technique specifically designed to make use of the *HTC Vive* controllers.

4.1. Volume manipulation

In a real world, people grasp objects with their hands and inspect them by hand and arm movements. We want to translate this natural interaction technique to the virtual setup in order to offer the user the possibility of inspecting the volume model without user movements. This interaction technique works as follows: First, the user has to move the right controller inside the volume dataset while pressing any button of the controller. While the user is pressing any button, the tracked controller movement is transferred to the volume dataset. In this way the user perceives the volume model as attached to her hand following her arm's movements (Figure 2 describes this grasping metaphor). As we will show in Section 5 this

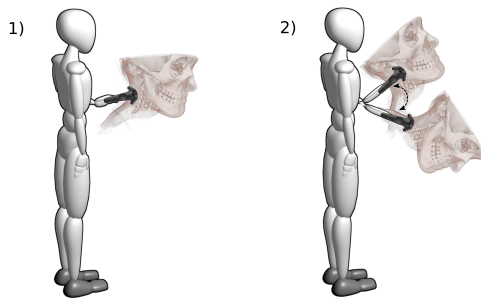


Figure 2: Block diagram showing the workflow of the grasping task. (1) First the user has to move the controller inside the volume model and press any button. (2) While pressing the button, the user's arm movement directs the location of the model.

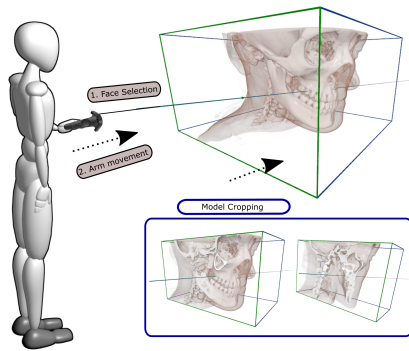


Figure 3: Block diagram illustrating the workflow of the crop task: (1) First, the user has to select the bounding box face she wants to resize. (2) While pressing the corresponding button and performing arm movements backward or forward, the bounding box is resized.

technique has been considered a very intuitive and efficient way of changing the location of the volume dataset.

4.2. Cropping the volume dataset

With respect the inspection of a volume dataset, the user has to have the possibility of visualizing its interior without having to move himself inside it. We have developed a some basic way of cropping the part of the volume dataset users want to inspect. The metaphor consists of resizing interactively the bounding box of the volume dataset. First, the user selects the face of the bounding box he or she wants to resize. While pressing any button of the right controller the user can interactively resize the bounding box moving back or forward the arm that holds the controller (Figure 3 describes the cropping metaphor). In this way he or she has the perception of pushing or pulling the bounding box face. As we will show in Section 5 this technique has been considered to be a enough intuitive and efficient way of cropping the volume dataset.

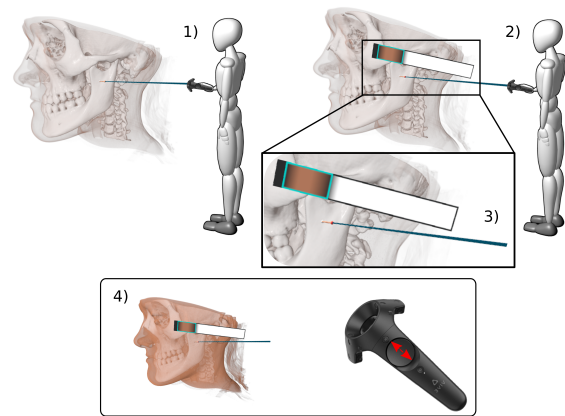


Figure 4: Block diagram illustrating the workflow of the TF modification task: (1) First, while pressing the corresponding button, the ray visualization is enhanced with the intersected materials. (2) User has to release the button when the material she wants to change the opacity has been traversed by the ray. (3) Then, the TF of the corresponding materials (their colours) is shown in a 3D panel attached to the controller. Using the joystick of the controller, the user is able to choose the desired material. (4) Finally, using the wheel provided by the joystick, the user can change its opacity.

4.3. Transfer function modification

Although normally, when inspecting a volume dataset in VR the TF (the specification of color and opacity to the different materials presented in the volume model) used is previously determined (because changing it interactively using a 3D widget could be very tedious and time-consuming task), we want to offer the users the possibility of changing the opacity of the materials presented in the TF used in the rendering. We have accomplished this task as follows: Initially, the user may explore the volume dataset interactively to set the best view for the next *opacity modification task* (see Figure 4.1). When the user presses the corresponding button of the controller, the task starts and the visualization of the ray emerging from the controller is enriched with a visual representation (spheres) at the intersection points of the ray with a new material. Throughout this process (while the user is pressing the button) the system continuously computes and visualizes the proper intersected materials (spheres set). Upon button release, the last ray shown is locked. The nearest point is marked in red and in front of the controller a canvas shows a visual representation of the TF used with the selected material highlighted in cyan (see Figure 4.2 and Figure 1). Using the joystick provided by the controller, the user is allowed to modify the opacity of the selected material (see Figure 4.3). The trigger provided by the controller allows the user to cycle among all the materials traversed by the ray. As we will show in Section 5, this technique has been evaluated as the most complex task among all the tasks evaluated in terms of the learning process. However, users consider this technique an effective way of changing the current rendered structures of the volume dataset.

5. Evaluation & Discussion

We have conducted an informal user study to evaluate user preferences. It consisted in performing an exploration of a specific medical model (see Figure 1) testing all the developed functionalities. 13 subjects participated in the evaluation, ranging between 20 and 70 years old. Subjects were asked to classify (as Low, Medium or High) their previous experience in VR applications and their expertise in 3D volume models applications. All of the participants were people from our department computer scientists at different levels of studies (master and PhD students) and faculty staff. After testing all the possibilities, participants filled out a questionnaire and indicated their level of agreement or disagreement with each statement using a 5-point Likert scale, where 1 meant the worst value and 5 was the best value. The results are shown in Figure 5. The answers seem to indicate that the proposed interaction metaphors are easy to learn and to use. None of the participants in the study had any problem in understanding the techniques and in using them. Although we got a positive feedback, users considered that the exploration metaphor could be accomplished without having to have the controller inside the volume model. One possibility could be to add other exploration paradigms such as the ones proposed in [KSKT13], for instance. We consider that our user-centered method is a very easy to learn technique so changing its natural behavior could reduce its effectiveness.

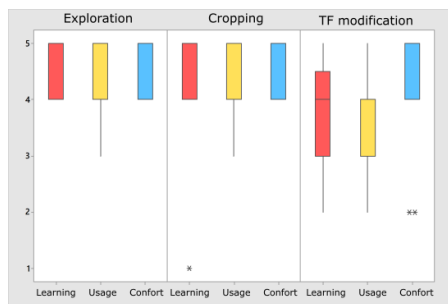


Figure 5: Results obtained from a personal preference evaluation questionnaire. The boxes show the interquartile range with the median as the horizontal bar. The whiskers extend to the minimum and the maximum of the data. These results show that the user preferences are quite positive with respect to the proposed techniques.

6. Conclusions & Future Work

In this paper we have presented an immersive system for the exploration of volume models using an HTC-Vive device. Our system allows the interactive inspection of a volume dataset while introducing some interactive model manipulation in order to achieve a better comprehension of it. Our evaluation shows that our application is perceived usable, easy of learn and very effective in terms of the high level of immersion achieved. In future, we want to re-design different interaction techniques thought specifically for a semi-immersive VR setup to be considered effective in a immersive VR setup.

7. Acknowledgments

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