Extending a Virtual Reality Nasal Cavity Education Tool with Volume Rendering

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***Abstract*—Answering the question whether virtual reality (VR), thanks to its ability to invoke real three-dimensional sensation in users, can improve the learning of spatial structures compared to traditional methods requires well-designed VR applications. We aim to investigate this question through a VR education tool that teaches the structure of the human nasal cavity. Our earlier studies suggested that an important feature of such VR education tools should be to give the context of the nasal cavity, i.e. visualize the rest of the anatomy of the head. In this paper, we discuss our approach of a VR learning application that achieves this using direct volume rendering.**

Keywords—virtual reality, volume rendering, nasal cavity, education, learning

I. INTRODUCTION

An important difference between traditional and virtual reality (VR) based applications is the ability of the latter to create the sensation of being in a 3D world. This suggests that the benefit of using VR for education [1] is even higher when we teach 3D spatial structures. Researchers in earlier works have identified this potential benefit and suggested a VR education tool to teach the structure of the human nasal cavity and its inner airflows [2]. This system visualizes the nasal cavity as a standard triangular mesh and overlays a human face mesh model to provide basic visual context about where the nasal cavity is located.

Building on this result, we carried out a preliminary user evaluation with task-based elements to test whether learning in VR is indeed more efficient than learning via traditional methods [3]. While our preliminary results of VR not giving any advantages were rather surprising, we also obtained important feedback from the participants of our study, which suggests that the very limited contextual information (i.e. only the face model is shown in addition to the nasal cavity) made navigation in the 3D space and interpretation of the visualization rather difficult.

In this paper, we propose an extension of the mesh-based VR nasal cavity education tool of [2] with volume rendering. Volume rendering allows the 3D visualization of the anatomy of the entire human head in a stylized and transparent way, which could provide the contextual information that users were missing. The VR application described here will be used in future work to evaluate the effectiveness of VR-based learning of spatial structures.

II. RELATED WORK

Many examples of volume rendering applications can be found in the literature that explore applicability of this method in VR, however, their field of application is general, none of them target education. A common approach is to visualize isosurfaces of the data [4], which may produce high quality results but on the other hand, only a specific part of the data becomes visible, as standard isosurfaces are not transparent. In our case, we aim at visualizing the context of the nasal cavity and thus we use alpha blending with transfer functions that allow to visualize the entire head with all the regions visible. Previous systems that use transfer functions [5], [6] design their interfaces for the highly flexible parameterization of the transfer function using widgets and painting tools. In contrast, our nasal cavity education tool is highly specialized and thus the user interface to control the transfer function is much more limited and thus much easier to learn.

Slicing tools are important components of VR volume rendering applications, however, previous systems allow only axis-oriented clipping planes that are controlled through widgets [4] or picking [5]. Our application, on the other hand, allows to place arbitrary clipping planes through a more natural interface, which we believe is an important requirement for the exploration and learning of 3D structures.

As VR requires high resolution images with high framerate, a common property of these systems is that the actual rendering code is implemented in GPU code [4]–[7], similarly to our application. While these are standalone applications tailored for the target platform, we integrate our application into a game engine, thus making it much more platform independent.

III. IMPLEMENTATION

Our system design was guided by three different aspects. First, the VR tool had to be capable of showing the nasal cavity and clearly distinguishing it from other parts of the head while also giving information about its context, i.e. rendering the rest of the head. This can aid the user in the navigation inside the head and provide a better understanding of the size and location of the nasal cavity w.r.t. the skull. In order to achieve this goal, the human head was visualized with direct volume rendering of a Magnetic Resonance Imaging (MRI) scan, with spatially varying rendering parameters based on the 3D segmentation of the nasal cavity. We used MRI data because it has much higher contrast-resolution compared to other modalities such as

Computed Tomography (CT) and thus better separates different tissues.

Second, we aimed at implementing our tool at a flexible and powerful multi-platform game engine that allows us to easily extend our system, port it to different platforms (e.g. mobile platforms) or integrate with our other education tools.

Finally, the main focus of our interface design was to allow free exploration and discovery of the human head and its nasal cavity without overwhelming the user with numerous options, controls and UI elements. Thus, we preferred mostly fixed but carefully designed visual styles and minimal but intuitive controls.

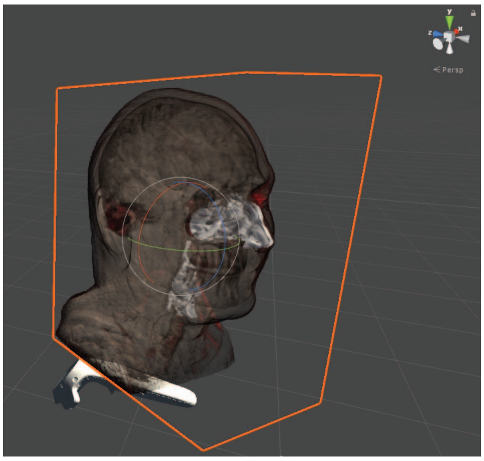


Fig. 1. Object with a volume rendering shader in the Unity scene editor.

A. Game Engine Integration

We implemented our system in the Unity game engine [8]. We defined a type of game object that renders a 3D scalar field, i.e. volumetric data, with direct volume rendering. The bounding box of the volumetric data is composed of a Unity mesh, which makes the volume renderer game object behave identically to any other game object in terms of properly showing the bounds of the object in the scene editor, occluding other game objects. Colliding geometry is also automatically assigned to allow participation in physical computations or ray casting etc. The rendering was implemented by drawing the bounding geometry with a pass-through vertex shader and implementing the ray casting in the fragment shader. We used front face culling thus, the farther sides of the bounding geometry invoke the fragment shader which makes it possible for the virtual camera – and thus the user – to step into the volume which we believe an important requirement for the proper understanding of the geometry of the human head.

As the head with volumetric rendering is a transparent game object, it has to integrate to the game engine as other transparent objects. We used depth-based compositing, similarly to [4], which modifies the endpoints of the rays during ray-casting based on the Z-buffer that contains depth values of the nearest object among all the standard game objects in each pixel. Fig. 5 (C) and (D) show the volume rendering composited with an opaque and a transparent Unity mesh object, respectively.

B. Transfer Function and Rendering Modes

We used accumulation-type ray-casting, i.e. we accumulate color and opacity along camera rays (a.k.a. alpha blending). This requires a carefully designed transfer function that maps data values of the MRI scan to color and opacity in a way that fulfills our goal of emphasizing the nasal cavity while also providing visual hints about the surrounding tissues.

In order to separate the nasal cavity from other organs we segmented the MRI data. However, MRI suffers from the so-called global signal fluctuation [9], i.e. as opposed to CT scans data values do not unambiguously identify a tissue type and even data values corresponding of the same tissue type may vary largely across the head, which makes segmentation a difficult task. We note that several segmented and labeled MRI atlas samples are available online, however, we decided to a real MRI scan as it turned to be more attractive to users in our preliminary studies.

We created two different segmentations manually, using ScanIP [10]. First, we created a label map that separates the head from everything outside it. This way, regions filled with air (such as the nasal cavity) can be distinguished from the air surrounding the head. Fortunately, air has always lower data values than soft tissues and thus in our transfer function we assigned high opacities to low data values and vice versa, whereas everything outside the head was assigned zero opacity. In order to emphasize tissue borders, opacity was also modulated by the gradient of MRI values: we slightly lowered opacity for voxels with low gradient magnitudes and increased opacity for voxels corresponding to strong gradients. Colors were mapped in a similar way. Users are even more sensitive to noise and flickering in stereo rendering than viewing the same scene on a screen, thus, it was very important to use high quality gradients. We used linear regression [11], computed in pre-processing and interpolated tri-linearly during ray-casting to approximated gradients. We note that staircase-like artifacts may be still visible due to linear interpolation of the function values. As future work, we plan to adapt the work analytic approximation show in [12] to alpha blending style volume rendering.

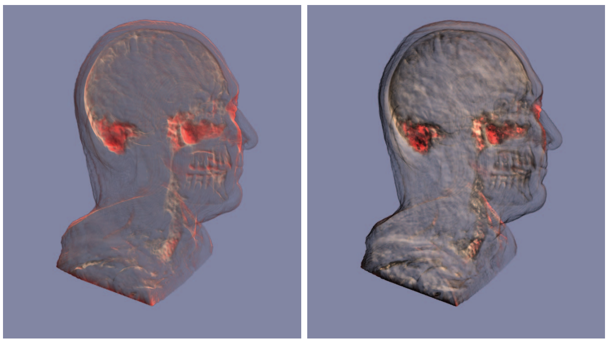


Fig. 2. Render result without (left) and with (right) ambient occlusion

We also obtained a segmentation of the nasal cavity, which may be used optionally to further emphasize the nasal cavity, which is illustrated in Fig. 5. Note that users may choose to render the head with only air chambers emphasized, or separating the nasal cavity either using a different color and opacity, or rendering a nasal cavity mesh in an opaque style (Fig. 5 (C)) or transparent (Fig. 5 (D)).

Volumetric ambient occlusion [13] was also implemented, which helps to better understand the geometry of the organs. Fig. 2 compares renders of the human head with and without ambient occlusion. We have chosen the method of Ruiz et al. [13] as it adds only a minor overhead to the rendering process while still producing high quality volumetric shadows. We note that ambient occlusion was computed on the raw MRI values, not considering the transfer function, i.e. shadows amplify the inherent boundaries of the raw MRI data. This has the benefit that ambient occlusion does not need to be recomputed when the transfer function changes.

C. Slicing and Slice Rendering

In addition to showing the direct volume rendering results, our system can also overlay 2D slices of the raw MRI data which may help in better understanding the anatomy. When slice rendering is enabled it also affects volume rendering, the part of the volume that is on one side of the slice plane is clipped. As opposed to [6], the slicing plane in our system may be arbitrarily oriented which we believe an important feature for learning.

For the rendered slice we defined three different types, which are depicted in Fig. 3. The first mode renders the slice as opaque, i.e. the volume rendering result behind the slice is completely occluded by the slice. In the second variant (Fig. 3. (B)), the slice is transparent and is blended with the volume rendering, which allows the 3D structure to be slightly visible while examining the 2D slice. This mode can optionally emphasize strong contours (Fig. 3 (C)) by assigning vivid colours and high opacity to MRI voxels with strong gradient.

D. User Interaction

User interaction was planned to be simple with limited but intuitive options. We mapped all user controls to VR controller buttons and movements. We used the HTC Vive VR device to test our application and therefore key mappings were defined considering the key layout of the Vive controllers. The Unity engine abstracts the VR device and thus controls do not have to be designed for a specific device, however, due to differences between VR controllers, any key mapping may be slightly less or more intuitive with different controls.

Considering the transfer function, we fixed most of the settings in order to make the user concentrate on learning and exploration instead of dealing with the tedious setting of the transfer function. On the other hand, the system renders a previously known data – that is, the particular MRI scan we use – and thus the transfer function is already tuned for this data and this particular application. The system allows to change a global scale on all opacity values which makes the head object look less or more transparent. Users can also toggle between the modes how the nasal cavity is rendered (Fig. 5).

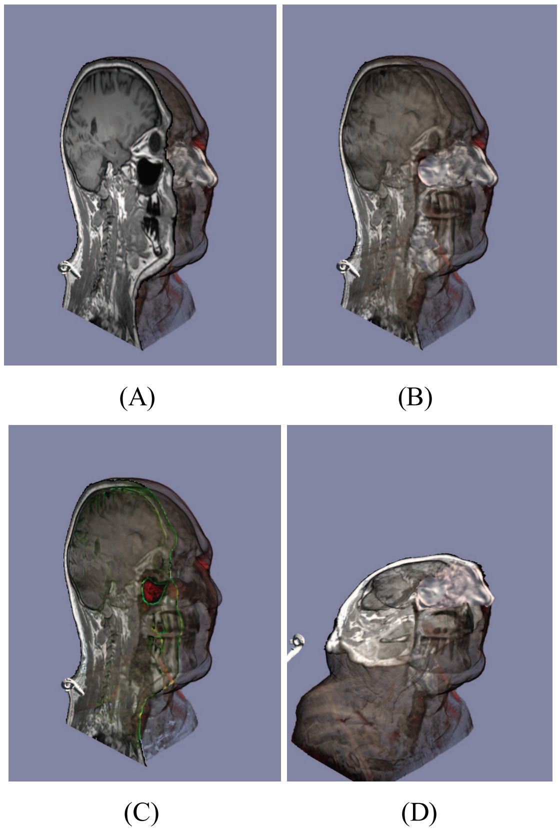


Fig. 3. Slicing tool: slice rendered opaque (A) and transparent (B), with contours highlighted (C) and a non-axis alligned slicing plane (D).

As we noted in Section III. C., the slicing tool allows planes with arbitrary orientation. We fixed the slicing plane to one of the controllers, this way the users can easily and intuitively rotate the plane. Plane modes (Fig. 3) can be toggled using a specific controller button. We also implemented a highlighting tool, similar to [4]. The other controller that is not controlling the slicing tool controls the 3D position of a point light source, which modulates voxel colours during volume rendering, using standard diffuse lighting principles (Fig. 4). As future work, we plan to experiment with 3D learning objects [1] to improve the quality of user interaction and the learning process.

Initially, the size of the head is approximately 2 meters to let the user to be able to step inside it completely. However, this size may not be optimal to understand every aspects of the anatomy, so we allowed the users to resize the head with opening or closing their hands while pressing a specific button

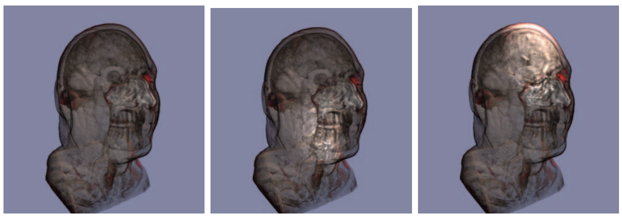
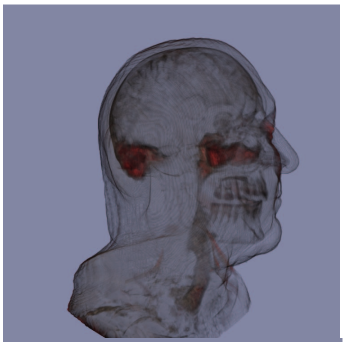
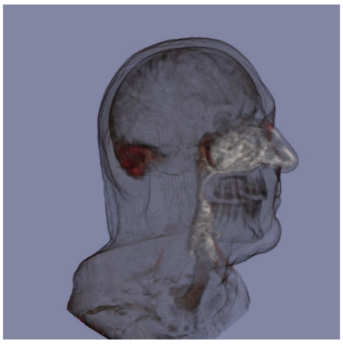
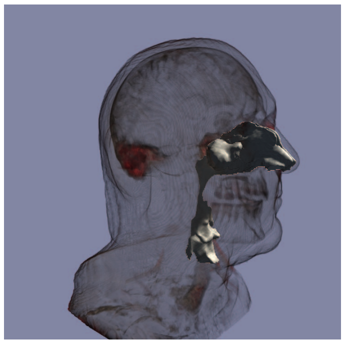
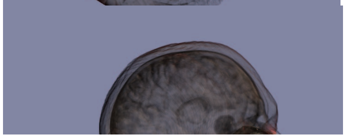


Fig. 4. Highlighting tool: original render (left) and highlighting a part of the mouth (middle) and the top of the head (right)









on both of the controllers. Although rotation could have been implemented in a similar manner, we wanted to encourage users to walk around the data and explore it "physically".

IV. Conclusion and Future Work

This work presented our approach for a VR anatomy education tool based on volume rendering and specifically designed to teach the anatomy of the human nasal cavity. The main motivation behind the application was to aid the users to feel the context of the nasal cavity by overlaying a transparent stylistic render of the entire head.

The main goal of this ongoing research is to answer whether and how VR and volume rendering can aid the learning process of spatial structures, such as the human nasal cavity. Thus, as future work, we shall evaluate the presented system with students, considering the following aspects:

- To study the effectiveness of the VR-based education, task-based evaluation shall be carried out in addition to the standard questionnaire-based user tests. An open question is how to measure and quantize the acquired knowledge of 3-dimensional structures. Written tests on a 2-dimensional medium may not be the appropriate form to evaluate spatial knowledge. We may also use tasks in the 3D space, including navigation or sculpting. As a side benefit of our studies, we may also learn more about the most appropriate way of evaluating spatial knowledge.
- The inclusion of volume rendering to our education tool was in response to user feedback. Although it is important to make the users feel comfortable while using such applications, it may turn out that giving the spatial context of the head in fact does not affect the learning rate. Therefore, to see whether volume rendering is beneficial in this context, we plan to compare the solely mesh-based application with the application presented in this paper.

We believe that learning more about any of these two aspects would allow us to develop more effective educational tools in the future, either with or without VR.

V. Acknowledgment

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References

[1] E. Mangina, "3D learning objects for augmented/virtual reality educational ecosystems," in 2017 23rd International Conference on Virtual System & Multimedia (VSMM), Dublin, 2017, pp. 1-6.

[2] S. Marks, D. White, and M. Singh, "Getting up your nose: a virtual reality education tool for nasal cavity anatomy," in SIGGRAPH Asia 2017 Symposium on Education. ACM, New York, USA, 2017, pp. 1-7.

[3] S. Marks, D. White, M. Magdics, "Evaluation of a virtual reality nasal cavity education tool", in IEEE TALE2018 International Conference on Teaching, Assessment, and Learning for Engineering, Wollongong, NSW, Australia, 2018, in press.

[4] A. Kratz, M. Hadwiger, A. Fuhrmann, R. Splechtna, and K. Bühler, "GPU-based high-quality volume rendering for virtual environments," in International Workshop on Augmented Environments for Medical Imaging and Computer Aided Surgery (AMI-ARCS), 2006.

[5] I. Scholl, S. Suder, and S. Schiffer, "Direct volume rendering in virtual reality," Bildverarbeitung für die Medizin 2018. Springer Vieweg, Berlin, Heidelberg, 2018, pp 297-302.

[6] J. Schulze-Döbold, U. Wössner, S. P. Walz, and U. Lang, "Volume rendering in a virtual environment," in Proceedings of the 7th Eurographics conference on Virtual Environments and 5th Immersive Projection Technology (EGVE'01). Eurographics Association, Aire-la-Ville, Switzerland, Switzerland, 2001, pp. 187-198.

[7] C. Hänel, B. Weyers, B. Hentschel, and T. W. Kuhlen, "Interactive volume rendering for immersive virtual environments," in 3DVis, 2014 IEEE VIS International Workshop on 3DVis, 2014, pp. 73-74.

[8] Unity Technologies, "Unity - Game Engine," 2018, https://unity3d.com/

[9] B. Csébfalvi, J. Koloszár and Zs. Tarján,. "Vector Quantization for Feature-Preserving Volume Filtering," VMV, 2004, pp. 363-370.

[10] Synopsys Inc., "Simpleware ScanIP – 3D image processing software from Simpleware, " 2016, //www.simpleware.com/sotware/scanip/

[11] L. Neumann, B. Csébfalvi, A. König, and E. Gröller, "Gradient estimation in volume data using 4D linear regression," Computer Graphics Forum. vol. 19, no. 3, Blackwell Publishers Ltd, 2000.

[12] P. Józsa, M. J. Tóth, and B. Csébfalvi. "Analytic Isosurface Rendering and Maximum Intensity Projection on the GPU," in Winter School of Computer Graphics, Plzen, Czech Republic, 2014.

[13] M. Ruiz, L. Szirmay-Kalos, T. Umenhoffer, I. Boada, M. Feixas, and M. Sbert, "Volumetric ambient occlusion for volumetric models," The Visual Computer, vol. 26, 2010, pp. 687-695.