

Volume Lens: Exploring Medical Volume Datasets using Mobile Devices

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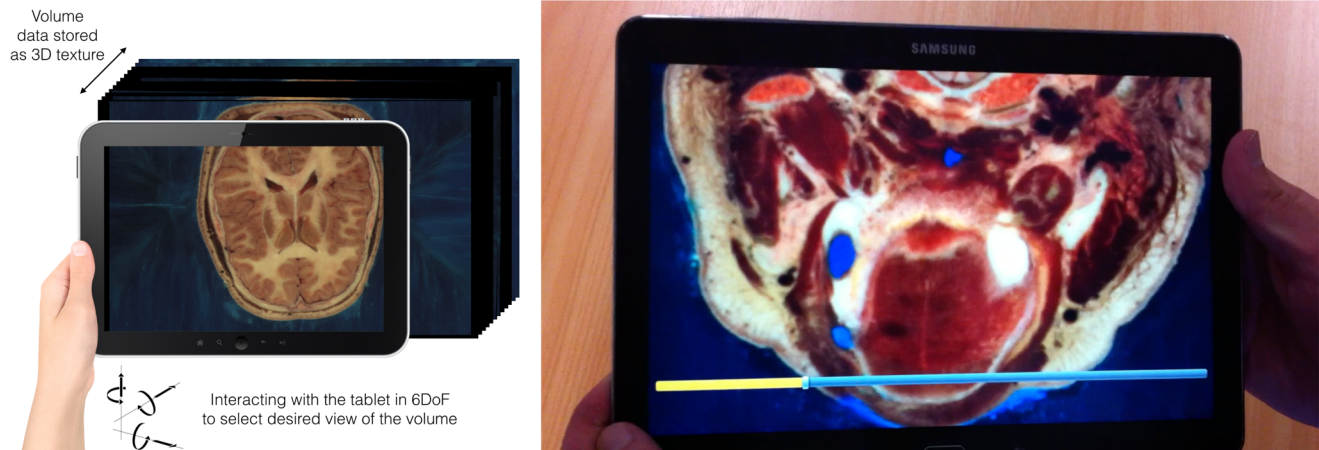


Figure 1: Illustration of the implemented prototype. (Left) Interacting with the tablet in 6 Degrees of Freedom allows user to select the desired view into the 3D volume. (Right) Actual photo of the developed prototype while in use. The volume is initially displayed at 1:1 scale but using the slider allows to zoom in or out for additional information.

ABSTRACT

Volume data representations are widely used in many different domains including medical imaging. Here, they are primarily accessed using WIMP interfaces on desktop PCs, while the use of handheld mobile devices to browse volume data is widely ignored. In this work, we present Volume Lens, an approach for displaying volume datasets on mobile hardware by implementing a novel interface that turns the mobile device into an exploration tool. The user can physically interact with the mobile device to interactively slice through the displayed virtual volume. The displayed slice is based on the position of the mobile device within the environment. We present our approach together with a explorative study gaining feedback from experts in the medical domain.

Keywords: Volume Lens; Volume rendering; Mobile; User study; Magic Lens.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities; H5.m. [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

1 INTRODUCTION

Imaging of 3D volume data is commonly used in many different domains such as medicine and geological surveying. Compared to traditional surface-based 3D data used in Computer Graphics, volume data represents a vast amount of information. The sheer size of this type of data makes it computationally expensive to process.

Until recently, this has restricted its use to mainly graphic intensive desktop computers where volume data can be interactively visualized. Recently, mobile hardware has become more powerful to the extent where it is possible to store and render volume data on off-the-shelf handheld mobile devices [6]. However, so far the volumes were relatively small and the performance was often not enough for real-time applications. Consequently, many groups investigated approaches to speed up volume rendering on mobile devices [6,8,9,11].

At the same time, we see a trend that more and more professional applications run on mobile devices, such as tablets, turning them from gadgets to productive tools. This can be particularly useful for professionals such as medical doctors [12] and medical students [10] who are often working away from their desk. Tablets have also been shown to have a high acceptance from patients as they allow physicians fast access to their medical files while still paying attention to the patient [14]. For medical students, visualizing and learning the human anatomy in 3D is a difficult task [2]. They typically learn about the human anatomy using cadavers to gain an understanding of the three-dimensional structure of the human body and to develop spatial reasoning skills necessary to understand and interpret volumetric imaging data [2].

In this work, we combine these factors by exploring a new interaction away from classic WIMP interfaces to display and explore volume data on mobile devices enabling an intuitive interface. The interface can support medical professionals and students by providing a 3D interface to volumetric 3D data that can be useful for exploration and examination or to learn about the human anatomy. Here, it can be complementary to exploring cadavers (which can be only done in a limited number) by still presenting the accurate spatial relationship of anatomical details. Our work is similar to magic lens interfaces revealing hidden information using Augmented Reality (AR). Magic lenses were initially introduced as a concept of “incorporating visual filters that modify the presentation of application objects to reveal hidden

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information and enhance data of interest” [1]. Looser, for example, presented a magic lens interface that can be used to interact with the virtual content displayed in an Augmented Reality [5]. This work was extended by Kalkofen et al. who showed how magic lenses can be used to apply different visualizations in AR to highlight context-specific information [3]. Contrary to these AR magic lenses, Viegas et al. introduced the term volumetric lens which is not 2D magic lens but a 3D magic lens in a Virtual Reality environment [16].

However, in this work we do not implement an AR interface overlaying the digital data onto the environment [4] or 3D magic lens [3], but focus having a magic lens into volume data by slicing the virtual volume data using the pose of the tablet in the environment (see Figure 1). This allows browsing of the volumetric data by giving the user a feeling of the 3D nature of the displayed data. We were, furthermore, particularly interested in how domain experts from the medical domain that often work with volumetric data would perceive our created prototype. We present our preliminary findings demonstrating the high interest in this kind of interface with relevance particularly for educating medical students in fields such as anatomy. Overall, our contribution is 1) the implementation of a novel interface allowing the user to explore volume data using mobile devices and 2) the evaluation by domain experts providing feedback on the developed interface. To our best knowledge there is no work exploring the unique interaction techniques offered by mobile devices when it comes to displaying volume data. Furthermore, there is a lack of knowledge on how domain experts would receive these novel interaction techniques. The closest work to ours is the work by Seyed et al. [15]. Differently to our work they used only the orientation sensors from tablet device to slice through the volume data (only 3DoF) while we are using computer vision to compute our pose in 6DoF allowing full control over the currently selected area of the volume data while also not suffering from inaccuracies such as drift in the sensors.

2 APPROACH

What is the point of three-dimensional data if it doesn't feel 3d to the user? We have implemented an approach that allows the user to physically explore volume data by way of physically moving a tablet device through the volume. They are able to do this interactively and in real-time. The volume dataset is stored on the tablet and is mapped into the user's environment based on the actual physical dimensions of the volume. The user is able to move or rotate the mobile device with 6 Degrees of Freedom (DoF) to gain different views of the volume data. The slice of the volume data that the user is viewing is the real-scale of the data. This interface allows the user to physically interact with the data in the three-dimensional space and is to the best of our knowledge a novel contribution. To implement a prototype that allowed us to investigate our approach, we faced three main challenges: a) the preprocessing of the volume data so that it can be displayed on the mobile devices b) tracking the position of the device which is used in c) the final rendering stage to compute the current view into the volume.

2.1 Implementation

Only recently has mobile hardware become powerful enough to interactively render volume data [9,11]. However, the large size of volume data still poses a challenge for many mobile devices, particularly, as the data should be kept in the GPU memory to allow for fast interactive rendering. One solution to overcome this problem is to build up a caching approach that organizes the volume data into small chunks which are interactively pushed to the GPU memory in case they are currently needed for display or kept in memory in case they are currently not needed to compute the

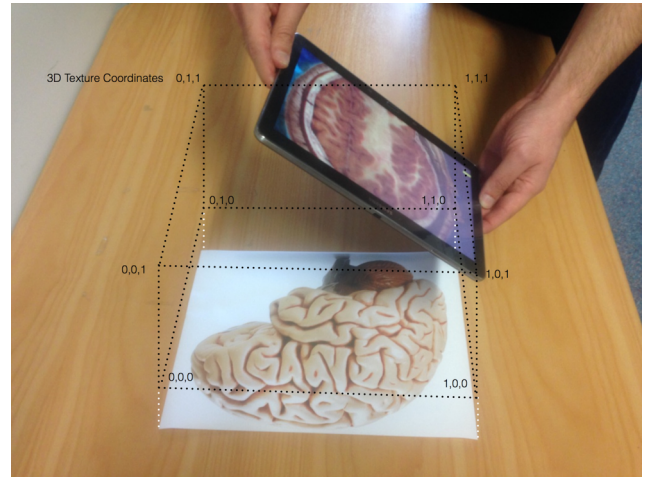


Figure 2: Illustration of the tracked and rendered volume. We positioned the virtual volume (black dotted line) 10cm above the tracked object (indicated by the white dotted line) to be able to browse all parts of the volume. Placing it closer makes it impossible to focus the camera on the tracked object

current image. This, however, would have presented a significant development overhead for our exploratory prototype so we decided to preprocess the volume data so that it fits into the GPU's memory. In our case, the dataset we used is from the Visible Human Project and is either 15GB (male) or 40GB (female) in size. We preprocess the data by reducing it to a given size by either reducing the overall resolution (which can be independently specified) and/or cropping the overall volume to smaller regions that can fit into memory. In our case the used mobile device (Samsung Galaxy TabPRO 10.1) offered 320MB of memory on the GPU which can be used to store our dataset while the remaining memory on the GPU was used otherwise and not accessible. We decided to reduce the initial dataset by cropping it to the head section and reducing the resolution leading to a final volume dataset which has a resolution of 799x508x200 pixels which is approximately 310 MB (each voxel represents RGBA as 4bytes). However, depending on the application or the device other datasets can be created within seconds of using the application.

2.2 Tracking of device position

To be able to correctly display the current portion of the volume data, we need to be able to track the devices position in 6DoF. We needed to track the tablet's position in the user's environment to be able to display the correct slice of the virtual volume to the user. There are several solutions for this such as marker-based tracking or tracking without visual markers (e.g. Simultaneous Localization and Mapping, SLAM). For our prototype, we decided to use the Vuforia Augmented Reality SDK as it is readily available even though we would envision a SLAM-based tracker for productive use of our system. Vuforia uses real-time pose tracking based on natural features (usually of a visual marker in the user's environment) to compute the pose of the devices camera with respect to the marker. This pose is used in the rendering stage to compute the current view into the volume which is based on the devices position relative to the tracked object.

2.3 Rendering the volume data

Given the medical context, we considered it to be important to display the volume in the correct size. This means that by default anatomical structures rendered on the display of the tablet are as

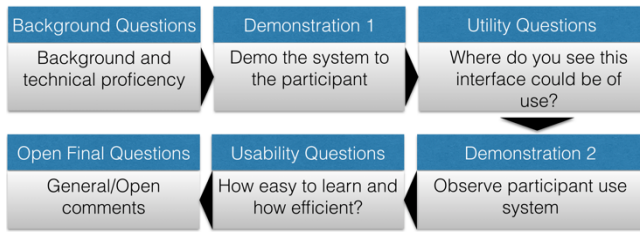


Figure 3: Steps of the expert study on utility and usability of the tracked and rendered volume.

large as they were in the original body when scanned. We achieved this by measuring out the proportions of the used tablet device and consider the scale when displaying the stored volume data. This is relatively straight forward as the dataset used in the Visible Human Project comes with a given scale which is 1mm side length per voxel for the male and .33mm for the female scan. We further needed to consider the tracking based on visible features when positioning the virtual volume data in space. If we would have placed the virtual volume to be explored, directly on the surface of the tracked object (e.g., table, marker) we would not be able to browse the areas close to the surface as the camera would be too close to the tracked object and consequently the images would be too dark and blurry to be tracked from. We therefore decided to place the virtual volume 10cm on top of the tracked surface to avoid this kind of problem (see Figure 2).

To accurately display the volume data, we firstly measured the position of the corners of the tablet computer in relation to the camera. Given the position of the camera in 3D space obtained from the Vuforia-based tracking, we can then compute the position of each corner of the tablet in 3D space using the pose matrix and the measure tablet dimension. Given the defined position of the volume data, we compute the corresponding 3D texture coordinates of each corner of the tablet computer (see Figure 2). These 3D texture coordinates are then used to render the selected view of the volume data. We render the volume data with OpenGL ES 3.0 and the whole approach including tracking and rendering the volume data runs with an average of 30fps on our target device (Samsung Galaxy TabPRO 10.1).

A final rendering of the brain’s anatomy can be seen in Figure 1 showing the frontal part of the human brain. Moving or rotating the tablet allows the user to interactively view other areas of the brain. A thin red frame will be displayed in case the tracking fails which happens if the tracked object is occluded. We furthermore added a slider which appears when touching the screen. The slider can be used to change the scale of the displayed data which is displayed at 1:1 scale per default.

3 USER EVALUATION

After finishing the implementation of our Volume Lens prototype, we were interested in collecting feedback from possible users. We were particularly interested in the feedback regarding the utility and usability of our prototype from experts in the medical domain.

3.1 Design

We chose to conduct our qualitative evaluation by having a semi-structured interview with neural anatomy domain experts. We recruited six medical experts for our user study mostly originating from neural anatomy or general anatomy. Five of the six participants answered that they were proficient at using a tablet computer. Given the time limitations of medical personnel, we decided upon conducting a qualitative evaluation as the small number of available participants will not allow for a quantitative analysis of the provided feedback. We also hoped that this qualitative feedback from domain experts would allow us to gain

an outside perspective on our interface and possibly discover aspects about it that we hadn’t considered. We started the interview off with background questions and then gave the participants a demonstration of the Volume Lens prototype with each participant receiving the same demonstration. After our demonstration, we asked question on utility of the Volume Lens prototype. We followed this by giving the interviewee the chance to use the Volume Lens prototype. After they determined they were acquainted with the application, we moved on to the usability questions. We finished the interview with concluding questions about features to be added and any general comments which did not fit into the other categories (see Figure 3).

3.2 Utility

A common theme brought up is the use of our interface for teaching medical students. When asking the participants about the utility of the application, five of the six participants said they could see it being used in education/teaching. They specified areas such as neuro anatomy, pathology, psychology and neurosurgical planning. One of the major challenges for students learning the neural anatomy is the “3D relationship between anatomical structures”. They explained that 2D material such as labelled 2D diagrams and 2D physical slices do a good job of teaching the 2D aspect of the anatomical structures, but the students struggle to combine these 2D resources into a 3D mental model of the structures. The majority of the experts indicated that by using our Volume Lens prototype to view the structures at different angles and being able to physically explore them would be helpful for students to understand spatial relation between structures and how “real” the visualization feels when used in our prototype. This statement was not confirmed by 1 of the experts who did not see any advantage for understanding the 3D relation of the data. The participants highlighted the responsiveness of the interface allowing them to get a quick idea of relationship between anatomical structures. In addition, participants felt that having the application on a tablet is an advantage as students and clinicians can easily bring the volume data with them on the move. One participant thought that the novelty of the interface would add to the experience of using it. participant felt that students would find the interface “fun”. In both cases the participants felt that these qualities would add to the user experience of students and make them more likely to use the application. Three participants see this application not only as useful for learning, but also for interpreting MRI and CT scans during their daily job.

3.3 Usability

Answers from the usability section of the interview were generally positive and indicate a user interface that is easy to learn, easy to handle and can be used effectively to teach anatomy based on displaying volume data. The majority of the participants expressed that they found the experience of using the application satisfactory. The two participants who didn’t express satisfaction seemed to be bothered by the lost tracking errors that occur sometimes. The general consensus was that it took a few movements to get used to the tracking and the movements that were possible and required to re-initialize the tracking. These observations and problems are in line with similar studies on tracking and magic lenses [7]. It was also mentioned that there are some views that are currently constrained by the tracking as a failed tracking prevents them from exploring a certain portion. Similarly, two participants found that a disadvantage of this particular interface is that it is hard to keep the current slice that they are viewing still. Interestingly, three participants expressed that they felt the sensitivity of the application was satisfactory. It seemed from observing the participants that some participants wanted to view still slices of the data while others enjoyed the dynamics and interactivity of the

system. A pause button was mentioned as a solution to satisfy both groups. It should be noted that two of our participants had experiences with augmented reality applications (which use a visual marker), so that would factor in to how quickly they were able to pick up the movements allowed. When asked about the efficiency of the interface, five of the six participants found that the interface allowed them to efficiently browse the volume data. All participants expressed that it was very easy to learn how to use. One participant summarized this by saying how the application used our natural 3D perception and this felt more natural than using a mouse/keyboard to interact with volume data. Opinions were generally positive about the resolution of the dataset and they felt the current resolution was acceptable for students as all they need to see are the structures that they are likely to need to know (membranes and capsules).

The suggestions for future features were changes that were relatively consistent throughout the interviews and stated that they wanted anatomical structures to be labeled as this could help students learn the structures. The zooming feature didn't seem as useful as we initially thought. When observing the participants using the device, they all seemed satisfied at the standard "real scale" (1:1) of the data and hardly used any other zoom level.

4 CONCLUSION AND FUTURE WORK

We have presented Volume Lens, a prototypical mobile interface for interactively exploring volume datasets. Our approach combines aspects of Volume Rendering and Magic Lenses to allow users to view cross-sections defined by the position of the mobile devices in space. Preliminary feedback from medical domain experts suggested applicability for medical education in particular in anatomy and when used complementary to other teaching material. The mentioned advantages were the better spatial understanding of the complex data provided by this interface as well as the general novelty and responsiveness. It was also mentioned that the interface can be efficiently used for browsing the dataset while also easy to use. The main drawback is the tracking that we would replace in future with a SLAM-based tracker which is known for better robustness while posing a higher development effort. Despite this drawback, our research shows the interest and requirements for novel interfaces in education and medical context given the ubiquity of mobile devices.

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