

Interaction with Medical Volume Data on a Projection Workbench

Ching-yao Lin¹, R. Bowen Loftin², Ioannis A. Kakadiaris¹, David T. Chen¹, Simon Su¹

¹Department of Computer Science
University of Houston
Houston, Texas 77204

{chingyao, ioannisk, ssu}@cs.uh.edu, bloftin@odu.edu, dave@chen.net

²Virginia Modeling Analysis & Simulation Center
Old Dominion University
Suffolk, Virginia 23435

Abstract

Interaction with volume data has often been difficult due to the large memory and processing power required. By taking advantage of current high-end graphics hardware, a volumetric virtual environment has been developed, which allows a user to interact with a volumetric visible human data set. The application enables the user to explore the interior of a virtual human body in a natural and intuitive way.

1. Introduction

In traditional data visualization, researchers visualize data on a two-dimensional screen and use a mouse and a keyboard to interact with the data. Recently, virtual reality (VR) techniques allow users to manipulate data naturally and intuitively in real-time. VR techniques have been applied to many areas of scientific visualization as well as training, one of the major areas is medicine. VR provides an intuitive way to visualize complex medical data, and can be used for medical education, surgery planning and training. In VR applications, the data are displayed in stereo mode, which allows users to better understand the spatial relationships between objects in the environment. In addition, the new generation of hardware allows interactive rates of interaction.

Traditional medical VR applications rendered scenes via surface graphics. Users build the anatomical models through modeling software or extract the surface information from volumetric data such as the ones obtained from magnetic resonance imaging (MRI), or computer tomography (CT) volumes through methods like the Marching Cube algorithm [1]. However, the heterogeneous inner structure of the human body cannot be displayed through surface graphics. Traditionally users studied their MRI or CT data as series of parallel slices, although the data are by their nature volumetric. The interior details of the human body can be presented using volume graphics. In the past, interaction in real-time with volume data was not practical due to the extensive computational power required. With the advent of fast graphics

acceleration hardware, we are now able to create an interactive volumetric virtual environment.

Three-dimensional interaction is a more natural and intuitive way to manipulate data. People can “feel” the position and movement of their hands without looking at them. To perform a task, a user’s perceptual system needs something to refer to, something to experience. Three-dimensional interaction uses a spatial reference to provide the perceptual experience [2]. Therefore, compared to a traditional keyboard and mouse interface, three-dimensional interaction provides an easier way to locate targets in a three-dimensional environment. For example, if we wish to select a clipping plane at an arbitrary angle in a three-dimensional environment, we can place the clipping plane at the desired location easily by just moving our hand. On the contrary when we use a mouse plus a keyboard, we have to adjust the plane’s orientation in a slow and cumbersome manner.

Our goal is to develop an application with the ability to visualize volumetric medical data [2] in a virtual environment at interactive rates, which will allow users to explore the interior of the human body. The application is intended for use in surgical training and planning.

2. Related Work

2.1 Projects based on the Visible Human Data Set

The Visible Human Project™ [3] is a long-range plan of the National Library of Medicine (NLM) to provide data that would serve as a common reference point for the study of human anatomy [3]. NLM has created a complete, anatomically detailed three-dimensional representation of the normal male and female body. The data were obtained using CT, MRI, and digitized photographic images from cryosection. The male was sectioned at 1-millimeter intervals while the female at one-third of a millimeter intervals [4]. There are many applications and products built on the Visible Human data set [5]. Most of those applications are rendering two-dimensional images directly or reconstruct new cross-section images from the original data set [6, 7].

Parker [8] describes a system which uses ray tracing of large volume data (Visible Woman from NLM), multiple CPUs, and shared memory.

2.2 Virtual Reality in Medicine

In this paper, we discuss two major categories of VR applications in medicine. A detailed survey of such applications can be found at [9, 10].

Virtual endoscopy: Virtual endoscopy is used as an alternative to the uncomfortable endoscopy procedure [11]. The three-dimensional CT and MRI data are used to reconstruct the human body to provide a visualization of a patient's specific organs [12, 13]. For example, in Virtual Colonoscopy [14, 15], the three-dimensional volumetric data are first reconstructed using a set of two-dimensional slice images, and then the surface information is extracted from the volume data by the Marching Cube algorithm. Parallel computation architectures and techniques have been used to improve the rendering rates.

Surgical simulation: The primary VR applications areas for surgical simulation include education, training, diagnosis, preoperative planning, rehearsal, and telemedicine [9, 11]. VR surgical simulators are designed to let young physicians examine the interior of a virtual body to learn anatomy and "practice" surgery [16]. Augmented reality (AR) also plays a very important role in surgical simulation [17].

3. Application Overview

3.1 Motivation

The benefit of volume rendering the Visible Human data directly from the volume data is the increased realism. Surface graphics only visualize surface information. That might lead to substantial loss of information. However, volume rendering provides information about inner structures also [18]. By taking advantage of the three-dimensional texture mapping hardware, one can interact with the volume data in real time.

3.2 System Setup

We built our environment on a custom-made immersive workbench with StereoGraphics®, CrystalEyes® shutter glasses, and a Polhemus FASTRAK® to track the movements of the user's hand (Fig. 1).

We are using the Visible Human male data sets in anatomical modes. These data include 1871 slices of 1760 x 1024 RGB tiff images. They also come with mask files, which contain the segmentation information of these data in different anatomical structures.

The basic idea of three-dimensional textures is to interpret the voxel array as a three-dimensional texture



defined over $([0, 1] \times [0, 1] \times [0, 1])$ and three-dimensional texture mapping as the trilinear interpolation of the volume data set at an arbitrary point within these domains [19]. Two-dimensional texture mapping uses bilinear interpolation and creates the three-dimensional view by adding all two-dimensional slices together. But then, it is necessary to create three different data sets along X , Y , and Z axes to prevent seeing the "gap" between two slices. By using three-dimensional texture mapping we maintain only one data set.

SGI™ OpenGL Volumizer™ is a graphics API that allows graphics applications to treat volumetric and surface data in a similar way [20]. In addition, it utilizes the three-dimensional texture-mapping hardware to accelerate the performance of applications. One very important feature is the ability to mix volume objects and geometric objects within the same three-dimensional scene. This feature allows us to use traditional surface graphics to create the user interface and still render the data using volume graphics.

There are many different choices to display objects in a virtual environment. Examples include HMDs, workbenches, and CAVEs. On one end, building a CAVE is very expensive, and at the other end, the resolution of HMD displays is very low. A workbench, however, is quite suitable for medical VR applications because it looks like a surgical platform and can display data in real-life size.

The basic idea behind the workbench is to have computer generated stereoscopic images projected onto the surface of the workbench [21, 22]. One user operates in the virtual environment while others can observe that operator's activities through shutter glasses. The "operator-observers" mode and the ability to share the same scene provides a good teaching and training environment.

Our working platform is a Silicon Graphics® Onyx2™ workstation with 64 MB texture memory. Images with size 256 x 256 x 256 in RGBA format can fit in the

texture memory and can be displayed fast to achieve the interaction required for the VR application.

3.3 Method

The full size of the original data bank is more than 3 GB. If we tried to display the full data set at one time, the performance would be very slow and we could not achieve acceptable interaction. During the data preprocessing stage, we scale down the resolution of visible human data set to fit in the Onyx2's texture memory. Then we add an alpha channel onto the data.

Seven different data sets were created. The first data set contains full body data in low resolution (220 x 128 x 232). Users can learn the global relationships of biological structures and functions by examining the full body data. The other six data sets are related to: head, left chest, right chest, middle chest, middle body, and lower body. These data sets were created at resolution of 256 x 256 x 128. The user can select different regions of interest via a three-dimensional selection box and s/he can examine particular parts in detail (Figs. 2 and 3).

Using the Visible Human's segmentation masks, we divided the visible human data into eleven groups. (i.e., circulatory, muscular, respiratory, articulations, nervous, digestive, urinary, integumentary, reproductive, endocrine, and skeletal.) The data set also contains complete information on the relative position of different human structures.

We developed a special interface which we call "segmented plane" which combines the spatial information with the anatomical data. In general, the segmented plane works like a clipping plane. However, instead of clipping all the parts away like a regular clip plane, the user can select whichever segments s/he would like to remove and examine the remaining parts (Fig. 4). We use the extra alpha channel to perform this task. By adjusting the values of the alpha channel of different segments, we are able to display different segments using different transparencies. Each time the user modifies a segment's alpha value, we re-scan the full set of segmentation information from the mask-file to find the corresponding position of target segments in the volume data. Then, we set the alpha value to the new values and update texture mapping.

The methods of interaction in our application include clipping planes and segment adjustable transparency. Interactive clip planes can remove unwanted parts completely and allow the user to see inside the volume. For example, adjusting the transparency level of different segment objects allows the user to see through skin or muscle.

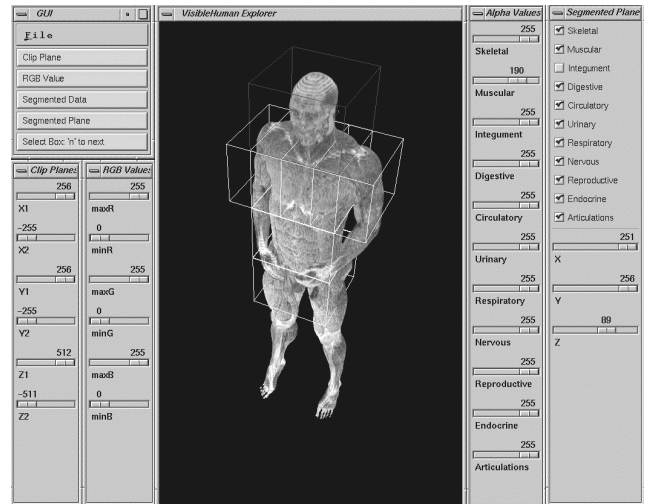


Fig. 2. Display of full body data with the selection box.

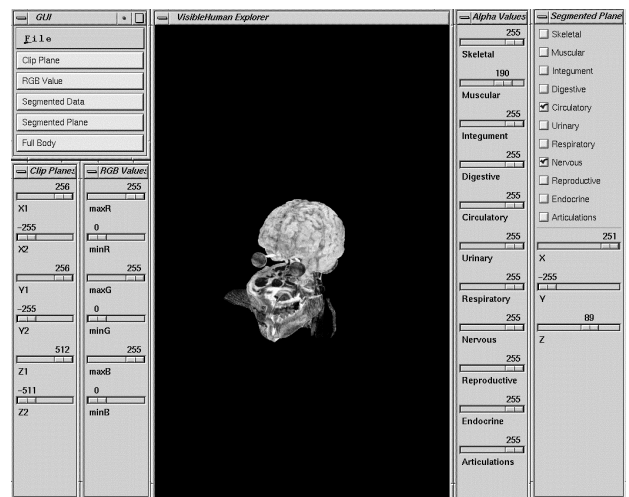


Fig 3. Display of the head in higher resolution

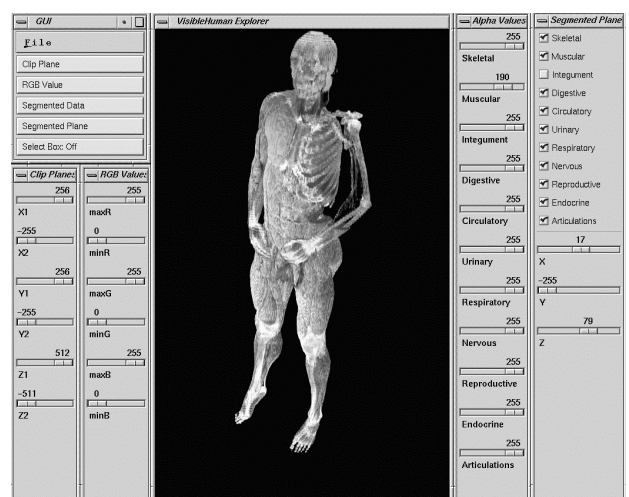


Fig 4. Display of the full body with different segments (skin and musculature of upper left body has been removed).

By rebuilding the virtual body through the Visible Human data set, we created a virtual human to allow students to study anatomy at their own pace for arbitrary lengths of time, since learning anatomy by dissecting cadavers limits a student's exposure to the information

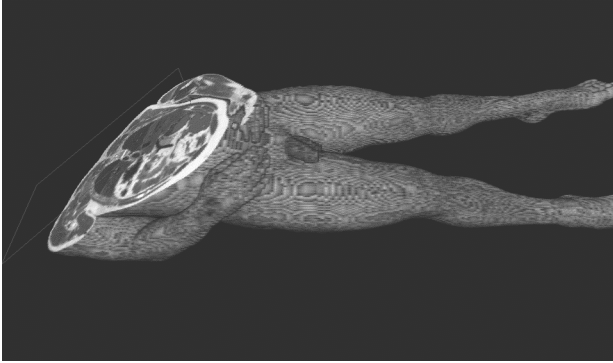


Fig 5. Display of full body on the table with a clipping plane selected



Fig 6. Another example demonstrating that we can select arbitrary clipping plane on the workbench



Fig. 7. Demonstration of our “segmented plane” concept

We have created two modes for our application. One mode displays the result on a monitor with mouse and keyboard input using a Motif GUI (Figs. 2 - 4). The other mode displays the result on the responsive workbench, and uses a Polhemus® Fastrak as tracking device combined with a 3D user interface to allow the user to interact with the data (Figs. 5 - 7).

The frame rate of our visible human explorer is 3.5 frames/sec for a 256x256x256 data volume, and a 800x500 viewport. It appears from statements of visiting doctors that this form would be acceptable to them. Because the data are stored on a remote file server instead of a local disk, it takes longer to load the data sets. Since the main memory of our Onyx2 is 256 MB, we cannot load the entire data set at one time. Our application needs roughly 500 MB of memory (64 MB/data-set * 7 data sets + segmentation information). The main bottleneck is the data loading time. It takes about 15 seconds each time we wish to load a different data set. We are currently experimenting with multi-resolution techniques to reduce loading time. Currently, the time needed to reconstruct data from low resolution to higher resolution is more than the I/O savings. Currently, we load the different data sets directly from disk.

4. Conclusions and Future Work

In comparison to traditional medical data visualization techniques, the main advantages of interaction with medical volume data using VR techniques are the following:

- Improving the understanding of spatial relations between objects in the scene by using stereoscopic mode.
- Providing the user an intuitive, convenient way to interact with volume data.
- Training routines can be performed repeatedly without the cost associated with actual dissections.

In this paper, we have presented a volumetric virtual environment, which provides a novel way to explore the inner structure of the human body. Although we are currently using a high-end workstation to achieve the interaction purpose, as new and cheaper workstations will become available, the interaction performance will be improved [23]. Our goal is to develop a volumetric virtual environment for education on the anatomy of the human body.

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References

1. W. E. Lorensen and H. Cline: "Marching Cubes: A High Resolution 3D Surface Construction Algorithm", *Computer Graphics*, vol.21, no.3, pp. 163-169, July 1987
2. K. Hinckley, R. Pausch, J. C. Goble, and N. F. Kassell: "A survey of Design Issues in Spatial Input", *ACM Symposium on User Interface Software and Technology*, pp. 213-222, 1994
3. The Visible Human Project®: <http://www.nlm.nih.gov/research/visible/>
4. M. J. Ackerman, "The Visible Human Project", *Proceedings of the IEEE*, vol. 86, pp. 504-511, March, 1998
5. NLM: Projects Based on the Visible Human Data Set, <http://www.nlm.nih.gov/research/visible/applications.html>
6. NPAC-3D Visible Human, <http://www.npac.syr.edu/projects/3Dvisiblehuman/VRML/VRML2.0/MEDVIS/>
7. S. Senger: "An Immersive Environment for the Direct Visualization and Segmentation of Volumetric Data Sets", *Medicine Meets Virtual Reality*, IOS Press, 1998
8. S. Parker, M. Parker, Y. Livnat, P-P Sloan, C. Hansen: "Interactive Ray Tracing for Volume Visualization", *IEEE Transactions on Visualization and Computer Graphics*, vol. 5, no. 3, 1999
9. J. A. Waterworth: "Virtual Reality in Medicine: A survey of the State of the Art". <http://www.informatik.umu.se/~jwworth/medpage.html>
10. A. S. Pednekar, V. Zavaletta, and I. A. Kakadiaris: "Application of Virtual Reality In Surgery Simulation", To appear in Indian Conference on Computer Vision, Graphics, and Image Processing (ICVGIP 2000), Bangalore, India, Dec. 20-22, 2000
11. Z. Soferman, D. Blythe, and N.W. John: "Advanced Graphics Behind Medical Virtual Reality: Evolution of Algorithms, Hardware, and Software Interface," *Proc. of the IEEE*, vol. 86, no. 3, pp. 531-554, March 1998.
12. R. Robb: "Virtual (Computed) Endoscopy: Development and Evaluation Using the Visible Human Datasets", *Proc. Visible Human Project Conference '96*, pp. 221-230, 1996
13. R. A. Robb: "Virtual Endoscopy: Evaluation Using the Visible Human Datasets and Comparison with Real Endoscopy in Patients", *Medicine Meets Virtual Reality*, IOS Press, 1997
14. S. You, L. Hong, M. Wan, K. Junyaprasert, A. Kaufman, S. Muraki, Y. Zhou, M. Wax and Z. Liang: "Interactive Volume Rendering for Virtual Colonoscopy", *Proc. IEEE Visualization '97*, pp. 433-436, Oct. 1997.
15. M. Wan, Q. Tang, A. Kaufman, Z. Liang and M. Wax: "Volume Rendering Based Interactive Navigation within the Human Colon", *Proc. IEEE Visualization '99*, pp. 397-400, October, 1999
16. R. M. Satava: "Virtual Reality for Medical Application", *ITAB '97, Proceedings of the IEEE Engineering in Medicine and Biology Society Region 8 Conference*, pp. 19-20. 1997
17. A. State, M. A. Livingston, W. F. Garrett, G. Hirota, M.C. Whitton, E. D. Pisano: "Technologies for Augmented Reality Systems: Realizing Ultrasound-Guided Needle Biopsies", <http://www.cs.unc.edu/~us/uswww/good.html>
18. A. Kaufman: "Volume Visualization: Principles and Advances", Course notes 24, SIGGRAPH '98
19. R. Westermann, T. Ertl: "Efficiently Using Graphics Hardware in Volume Rendering Applications", *Proceedings of SIGGRAPH 98*, pp. 169-177, July 1998.
20. OpenGL Volumizer, <http://www.sgi.com/software/volumizer>
21. W. Krueger, B. Froehlich: "The Responsive Workbench", *IEEE Computer Graphics and Applications*, vol 14, pp. 12-15, May 1994
22. G. Eckel, M. Gobel, F. Hasenbrink, W. Heiden, U. Lechner, H. Tramberend, G. Wesche, and J. Wind, "Benches and Caves", *ICON '98. Proceedings of the 24th Annual Conference of the IEEE*, vol. 4, pp 1996-1999, Sept. 1998
23. M. Haubner, C. Krapichler, A. Löscher, K. Englmeier, and W. V. Eimeren: "Virtual reality in Medicine-Computer Graphics and Interaction Technique", *IEEE Transactions on Information Technology in Biomedicine*, vol. 1, no. 1, pp. 61-72, March 1997