Hybrid-Reality: A Collaborative Environment for Biomedical Data Exploration Exploiting 2-D and 3-D Correspondence.

Marc Antonijuan Tresens and Falko Kuester
Visualization and Interactive Systems Group
University of California, Irvine
{antonijm, fkuester}@uci.edu

Abstract

Doctors and radiologists are trained to infer and interpret three-dimensional information from two-dimensional images. Traditionally, they analyze sets of two-dimensional images obtained from imaging systems based on x-rays, computed tomography, and magnetic resonance. These images correspond to slices or projections to a single plane. With the resolution of the scanners increasing in all directions, so is the complexity of the data that can be used for diagnostic purposes. Using volume rendering techniques, massive stacks of image slices can be combined into a single image and important features stressed, increasing the doctor's ability to extract useful information from the image. A hybrid visualization approach combining 2D slices and 3D visuals is presented, drawing from the best features of both of these approaches. 2D slices emulate conventional medical images while 3D images provide additional information, such as better spatial location of the features in the surrounding structures as well as the 3D shape of features.

Keywords: Virtual reality, hybrid reality, biomedical visualization

1 Introduction

Medical images are obtained with a variety of imaging systems such as X-Rays, magnetic resonance imaging (MRI), computed tomography (CT), optical coherence tomography (OCT), positron emission tomography (PET), and functional MRI (fMRI). Traditionally, image sequences were printed on semitransparent film and visualized on a lightboard. Assuming that these images are available in digital form, in combination with information about image alignment, it suddenly is possible to compute and visualize slices in not only orthogonally oriented directions but in any arbitrary orientation. It is also possible to combine consecutive slices to create a 3D volume. 3D visualizations of this volume data allows researchers to study its 3D structures and explore data from points of view not possible in the real world.

Both 2D and 3D visualization contribute in different ways to obtaining a better understanding of the dataset. The presented Hybrid-Reality system focuses on closing the gap between 2D and 3D for biomedical data visualization.

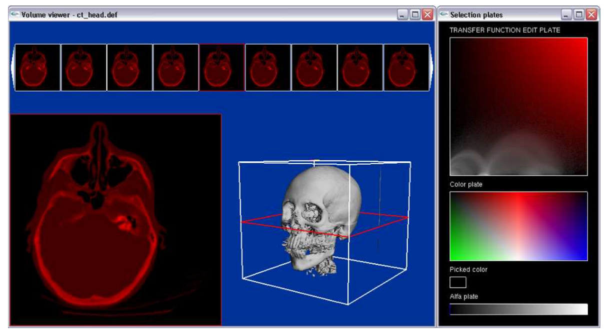

Figure 1: Interface of the application. 2D and 3D spaces and transfer function editing tool.

2 Related Work

2D and 3D visualization are complementary techniques for biomedical data interpretation. However, limited research has been performed in respect to fusing the advantages of both modalities, each contributing in different ways. Tory (2003a,b) and Preim and Peitgen (2003) have studied the benefits of each modality. Preim and Peitgen (2003) proposed a set of "golden" rules for medical visualization. The first rule states that while 3D representations are more useful as overview, 2D visualizations enable more accurate interaction. In addition, 3D representations are useful to determine the position and orientations of the 2D slices while 2D slices are good to reduce occlusions [Tory (2003a)].

Tory's work is focused on the mental registration between 2D and 3D visualization. She observes that this registration is done easily by using in-place displays, where the 2D slices are directly located in the 3D scene. However, this type of visualization, generally introduces more occlusion. Therefore, in our approach 2D slices are directly visualized in the 3D space (as a cutting plane) or in a separate space (2D space) to avoid occlusion while helping with mental registration. Tory also states that it is easier to register slices when they are oriented in the same direction, as they appear in the 3D image. However, the image may get distorted, making it more difficult to interpret the data itself.

The introduction of touch sensitive screens has opened new opportunities for biomedical visualization and interactive data analysis. For example, Hinckley et al. (1995) presented a study using a touchscreen combined with 3D props. The touchscreen was used to perform 2D operations and props were used for 3D interaction. They state that the touchscreen can substitute a mouse and keyboard while offering several advantages. A primary advantage is that it is not necessary to drop the props to start using the mouse or keyboard. Instead use the props or hands to interact with the touchscreen, thereby, removing the cognitive load associated with switching input devices. In addition, the use of touchscreens is more convenient in certain environments such an operating room where equipment should be easy to clean (sterilize) and use.

3 Hybrid-Reality

The presented Hybrid-Reality approach contains two main divisions, or spaces. The 2D space shows selected slices and the 3D space the corresponding volume rendered representation. The image shown in the 2D space can be selected in the corresponding 3D space in different ways, (1) by selecting the axis of an orthogonal oriented slice, (2) by positioning an arbitrary oriented slice or (3) by changing the slice number. The types of visualization shown in the 3D space are, (1) orthogonal and arbitrary oriented slices from any point of view, (2) isosurfaces with an interactively selected isovalue, (3) maximum value projected images, (4) progressively refined ray-casting volume rendered images, and (5) hardware accelerated texture based rendering. The last two techniques can be classified as volume rendering techniques, supporting transparency, to see through parts of the volume. In this case, good transfer functions are required, to emphasize the important features and discard irrelevant data. Our approach employs a pre-computed transfer function to determine color and transparency dependent on scalar and gradient values. In addition, the user can interactively edit the values of the transfer functions to emphasize particular features (see section 3.5). Cutting planes are provided as another standard tool to explore the internal parts of the volume. It is important to show the spatial correspondence between the slice shown in the 2D space and image shown in the 3D space. This helps the user to understand the spatial location of 2D slices in 3D space, and identify features from the 3D space that are present in the slice. For this reason, the Hybrid-Reality system always shows a bounding polygon of the 2D slice in the 3D space.

3.1 Hardware/set-up

The Hybrid Reality system was developed for a new type of visualization environment, called VizClass. The VizClass [Hutchinson et al. (2003)] is a collaborative environment that contains three touch sensitive screens (digital whiteboards) and one rear-projected passive-stereo display with a 10 feet diagonal display surface. This configuration enables collaborative work between research teams while providing simultaneous access to 2D and 3D content in adjacent mono and stereo projection spaces.

All screens are rear pojected, and users can walk freely in front of the screens without shadowing the images. The stereoscopic display provides passive stereo, therefore only polarized glasses are necessary to see in 3D. While wearing these glasses, users can smoothly transition between the mono and stereo display spaces without negative side effects to the image quality.

A cluster consisting of 8 PCs provides the needed computational resources and controls the devices of VizClass. In this project, the relevant workstations are three workstations that control the three SmarBoards, one worksation that contols the stereoscopic projectors and the server, that controls the overall system and communicates with a touch sensitive control screen located near the entrance. This screen allows a user to start and configure an application that will be running on the cluster. Figure 2 illustrates the system layout.

Figure 2: Picture of the VizClass. Stereoscopic screen (left) and touch sensitive screens (right).

All rendering techniques were specifically implemented for commodity hardware, equipped with consumer level graphics cards such as nVidia's GeForce 4 or ATI's Radeon family. While the use of traditional I/O devices is feasible, we have experienced that the use of more specific hardware can contribute in several areas. A touch sensitive screen provides a better interaction experience and it is possible to perform all the desired operations simply by using a stylus over the screen. In addition, to provide more precision for certain operations it is possible for multiple users equipped with individual styluses to collaborate freely.

If the user naturally wants to navigate in 3D, additional hardware is required. The Hybrid Reality framework provides support for 2.5D and 3D interaction devices such as gyroscopic mice and electromagnetic trackers.

3.2 Touch screen integration

To provide natural Human-Computer-Interaction, the Hybrid-Reality system utilizes the three touch-sensitive rear-projected whiteboards. The 72 inches diagonal touch-sensitive displays allow multiple users to view data simultaneously while interacting directly with the screen. A passive stylus is used for data input and although multiple users cannot draw at the same time, everyone can hold a stylus, and perform operations in quick succession.

Operations supported by the digital whiteboards include, (1) switching between slices, (2) changing the transfer function, (3) segmenting and labeling of image data, (4) navigation of the 2D and 3D space and (5) sketching for intuitive collaboration. Users can select image slices and the corresponding 3D visual through a set of image thumbprints, that are presented in traditional lighboard fashion (see Figure 1). By clicking with the stylus in one of the thumbprints the respective slice is activated. Changes to the transfer function, which is controlling the volume rendered images, are possible by simply drawing on the transfer function editor window to select features of interest. Since the images are updated immediately the user can keep refining the selected areas interactively. Users may also attach labels to either the 2D and 3D contents to aid with feature definition or image/scene segmentation. The correspondence between the 2D and 3D representation allows direct mapping of this information into the respective other space. The SmartBoard is equipped with a wireless keyboard and a software emulated keyboard that makes it possible to enter text with the stylus. Furthermore, this configuration supports sketch based input via "digital ink", which can help to point out interesting regions and to share knowledge with other users.

3.3 3D interface

Different stereo projection techniques are available today, including active, passive and autostereoscopic systems. Stereo visuals are achieved with one projector and shutter glasses (active stereo) or with two projectors and polarized glasses (passive stereo). 3D navigation in virtual environments requires additional interactive devices that allow the users to control all three dimensions. For the Hybrid-Reality system, we selected data gloves (pinch gloves) in combination with an electromagnetic tracking system. The data gloves act as a digital input device, whenever two or more fingers are in contact. The tracking system is equipped with four independent sensors that register position and orientation. Two of these trackers are attached to the gloves and the others to the users head. Subsequently, interaction with the data is possible through an intuitive two-handed interface supporting natural dexterity.

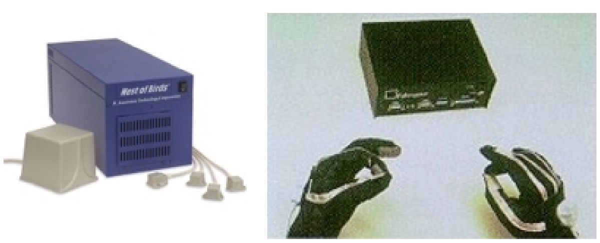

Figure 3: Nest of Birds and Pinch Gloves.

A variety of different finger mappings can be used with the pinchglove. The Hybrid-Reality system provides user definable "pinch-maps" that associate finger pinch events with actions or state changes. When the thumb and the index fingers are in contact a spherical proxy becomes visible on the screen. If the connected fingers are from the left hand, the sphere is green, otherwise, it is yellow. When only one hand has the two fingers pressed, the user can translate the object. When fingers of both hands are pressed, the user can rotate the object. The axis of rotation is defined in the middle point between the proxies corresponding to both hands. Note that the proxies position are related to the position of the trackers (attached to the gloves). Therefore when the hands are moved in one direction, the proxies will move in the same direction within the scene. Other finger combinations are used to change between rendering modes, lighting conditions and scene contents. Menu selection is currently possible thorugh direct interaction with one of the digital whiteboards. Since these boundaries are too constraining in the described environment a new generation wireless dataglove is being developed to overcome this limitation. At the same time, the use of gyroscopic mice showed a potential as a very cost effective alternative to traditional 3D trackers and interaction devices.

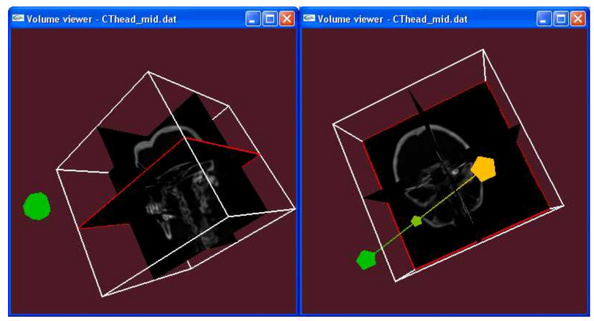

Figure 4: Spherical proxies rendered when thumb and index fingers are pressed. A connection line between the spheres and a smaller sphere representing the rotation axis are visualized when these fingers of both hands are pressed.

3.4 Volume Rendering

In order to visualize a volume, different approaches can be used. For example, in iso-surface visualization, the user specifies an iso-value and the surface that traverses all the points in the image containing this value are visualized. Another approach is what is called direct volume rendering. In this technique the whole volume is visualized. In order to capture the inner parts of the volume, some areas must be semi-transparent allowing parts behind them to be visible.

The Hybrid-Reality system provides support for iso-surfacing and direct volume rendering. For iso-surface rendering in software, the Marching Cubes Algorithm is supported [Lorensen and Cline (1987)]. We use two approaches for volume rendering. Ray casting [Levoy (1990) and Sabella (1988)] and 3D texture mapping [Van Gelder and Kim (1996)]. For ray casting the output can be computed by selecting the maximum value along each ray or by compositing the values along the ray depending on the transparency of each voxel that the ray passes trough. 3D texture mapping is based on loading the entire volume as a 3D texture into texture memory and rendering planes parallel to the viewport with texture coordinates of the 3D texture. While ray casting creates high quality images at the cost of rendering time, 3D texture mapping creates acceptable quality images at interactive rates. In order to make ray casting visualization interactive, the image is rendered first at low resolution and is subsequently progressively refined. This allows real-time rendering of an approximation while the user is rotating the image. Once the viewpoint remains fixed, the image is refined automatically.

The definition of the opacity values in direct volume rendering is a crucial duty in order to give an efficient visualization. These values will define which parts of the volume are visible and which parts are not. Colors are very useful to differentiate between multiple objects or materials. The transfer function defines both transparency and color depending on parameters of the data-set.

3.5 Transfer function

Transfer functions specify color and transparency values based on parameters of the data-set. We use a two dimensional transfer function, as defined by Kindlmann and Durkin (1998); Kniss et al. (2001, 2002). This transfer function depends on the scalar values and the gradient. The dependency in scalar values helps with separating different regions of the data-set and the gradient dependency aids with emphasizing the contours between these regions.

Frequently, it is a complex task to edit the transfer functions to obtain a desired visualization result. Preim and Peitgen (2003) stated in the second "golden" rule that is important to provide useful defaults for visualization parameters. This is particulary true for volume rendering. A good values should provide an image that give to the viewer a clear understanding of the data and only small changes are required to emphasize different features. The Hybrid-Reality system provides a default transfer function for color and transparency. The color is based on the density values of the original data-set. The transparency is based on the gradient of the same values. Therefore, contours are stressed (more opaque) and the areas with different density values can easily be differentiated.

The parameters of the transfer function can be edited in real-time. The user can select which values will be affected by the change of color and transparency. In order to guide the user a histogram is rendered in the area used to change the transfer function values. The histogram corresponds to the number of voxels that have a certain scalar value and gradient. Figure 5 illustrates an example of a two-dimensional transfer function. The x-axis corresponds to the scalar values and the y-axis to gradient values. The histogram is presented in logarithmic scale since some of the values (e.g. background) appear much more than others. The user can select a color and an opacity value and draw in this editing area, thus defining a squared region (limits for scalar and gradient values) that will have this color and opacity associated with it.

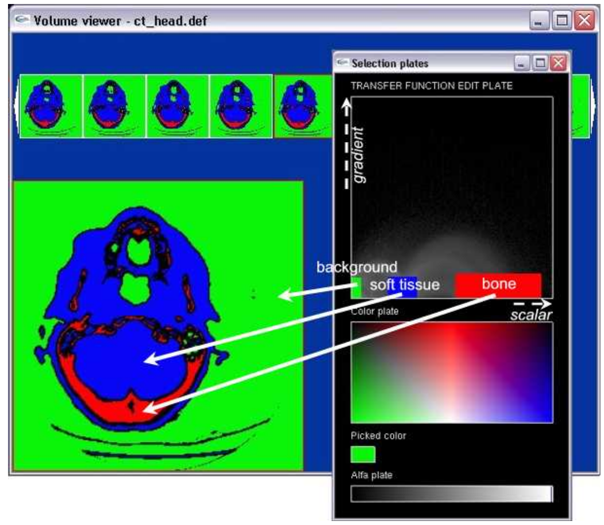

Figure 5: Two dimensional histogram (scalar values and gradient). The arcs correspond to transition between materials and the bases of the arcs correspond to relative homogeneous areas.

3.6 Annotation

It is possible to add, edit or delete labels directly on the screen. These labels allows users to add relevant information (in form of text) to the rendered data-set. These labels are attached to the corresponding 3D location and displayed in both 2D and 3D space.

Labels are most easily attached in 2D space and the system automatically stores the 3D location of the label by using the width and height components of the selected point and the depth component of the current slice. The label is then visualized in 3D space always facing the view-port (billboard). An example showing three labels can be seen in Figure 6.

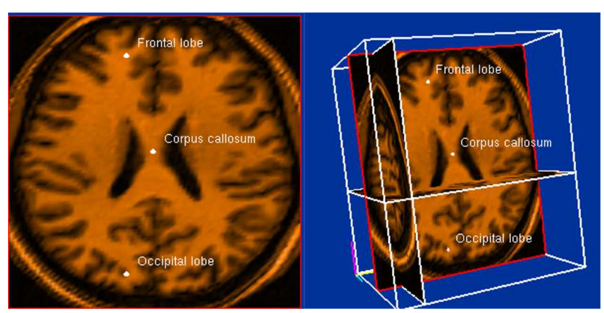

Figure 6: Interactive placement of labels in 2D and 3D.

4 Conclusions

In this paper we presented a hybrid reality approach for biomedical data visualization, combining 2D and 3D visualizations at the same time. The approach is to draw from the relation between the two views to help users to identify corresponding parts. This is facilitated through, (1) the use of boundary polygons that represent the 2D slice in the 3D rendering space, (2) annotations made in the 2D space appearing in the 3D space, and (3) slice changes in the 3D space resulting in 2D changes. In addition, the user can locate an arbitrary oriented cutting plane in the 3D world, supporting mental registration between 2D and 3D. The 2D space can be used to add labels or draw contours, while the 3D space is utilized to locate the current slice or analyze the data by changing its visual properties.

This approach provides a set of three-dimensional modalities for visualization including, slices, isosurfaces, volume visualization with a transfer function editor that enables real-time modifications of the visual parameters of the volume.

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