AUTOSTEREOSCOPIC DISPLAYS IN COMPUTER ASSISTED SURGERY

by

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AUTOSTEREOSCOPIC DISPLAYS IN COMPUTER ASSISTED SURGERY

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ABSTRACT

AUTOSTEREOSCOPIC DISPLAYS IN COMPUTER ASSISTED SURGERY

Using images for diagnosis, therapy and surgery is a widely used option as evidenced by many articles in the literature. In conventional systems standard two-dimensional (2D) displays are used to view the images even though the images are three-dimensional (3D) reconstructed.

In this study, we used a computerized surgical assistant whose core functionalities are provided by an open source software package called Slicer. Slicer uniquely integrates several facets of image guided therapy into a single environment and has capabilities for visualization, surgical planning and guidance.

We performed basic tasks of computer assisted surgery such as registration, segmentation, surface model generation and 3D visualization on medical images and displayed the reconstructed images on an autostereoscopic display so that the images with depth can be viewed without the need to wear any special eyeglasses or headgear.

Keywords: Autostereoscopic Displays, Slicer, Visualization, Computer Assisted Surgery.

ÖZET

BİLGİSAYAR DESTEKLİ CERRAHİDE OTOSTEREOSKOPİK EKRANLAR

Resimlerin tanı, tedavi ve cerrahide kullanılması literatürdeki birçok makalede de belirtildiği gibi yaygın bir durumdur. Geleneksel sistemlerde resimler 3-boyutlu (3B) olarak yeniden yapılandırılmış olsalar bile standart 2-boyutlu (2B) ekranlar kullanarak görüntülenir.

Bu çalışmada temel işlevleri Slicer isimli açık kaynak kodlu bir yazılım paketi tarafından sağlanan bir bilgisayar destekli cerrahi yardımcı kullandık. Slicer resim rehberli terapinin çeşitli kısımlarını tek bir ortam içinde eşsiz bir biçimde birleştirir ve Slicer'ın görselleme ile cerrahi planlama ve rehberlik için yetenekleri vardır.

Biz tıbbi imgeler üzerinde rejistrasyon, segmentasyon, yüzey modeli oluşturma ve 3B görselleme gibi bilgisayar destekli cerrahinin temel işlemlerini gerçekleştirdik ve yeniden yapılandırılmış imgeleri bir otostereoskopik ekran üzerinde derinlik sahibi imgeleri özel gözlük veya başlık takmaya gerek kalmadan izlenebilecek şekilde gösterdik.

Anahtar Sözcükler: Otostereoskopik Ekranlar, Slicer, Görselleme, Bilgisayar Destekli Cerrahi.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
API	Application Programming Interface
CAS	Computer Assisted Surgery
FDA	The US Food and Drug Administration
fMRI	Functional Magnetic Resonance Imaging
GPU	Graphics Processing Unit
GUI	Graphical User Interface
LCD	Liquid Crystal Display
MRI	Magnetic Resonance Imaging
MRML	Markup Language
NRRD	Nearly Raw Raster Data
SPGR MRI	Spoiled Gradient Echo Magnetic Resonance Imaging
XML	Extensible Markup Language

1. INTRODUCTION

1.1 Objective

Medical imaging has played an increasingly important role in surgical planning and treatment as it provides valuable information about anatomical structures and morphological functions. They are especially useful in minimally invasive surgery where specialized surgical instruments and arthroscopes are inserted through a small incision.

Medical image computing applications are complex pieces of software requiring a common set of base functionality as well as the ability to be customized for specific clinical applications. In a research environment, it is often necessary to make prototype environments that allow exploration and refinement of a new algorithm or concept in the context of a complete functional end-user application [1].

Computer Assisted Surgery (CAS) is the set of methods, that use computer technology for surgical planning, guiding or performing surgical interventions. Some common methods in the CAS systems include image processing and analysis tasks like registration, segmentation, model making and navigation. In most of the CAS systems, the 3D anatomical structures can be reconstructed properly by using advanced computer graphics algorithms but they are often rasterized into 2D arrays of pixels for display. Using a traditional 2D display may lead to difficulties in defining objects of interest or planning surgical paths [2]. Also during microsurgeries, surgeons use tools which can provide stereo view like microscopes but co-surgeons and assistant surgeons track the operation on 2D displays. The same problem is valid for endoscopy where doctors tract the operation on a traditional display, as well. Therefore, 3D displaying methods for surgery have become a focus of development in the field of CAS systems.

Manufacturers have been producing glasses-based stereoscopic (3D) display systems for decades, and usable glasses-free autostereoscopic systems have been available

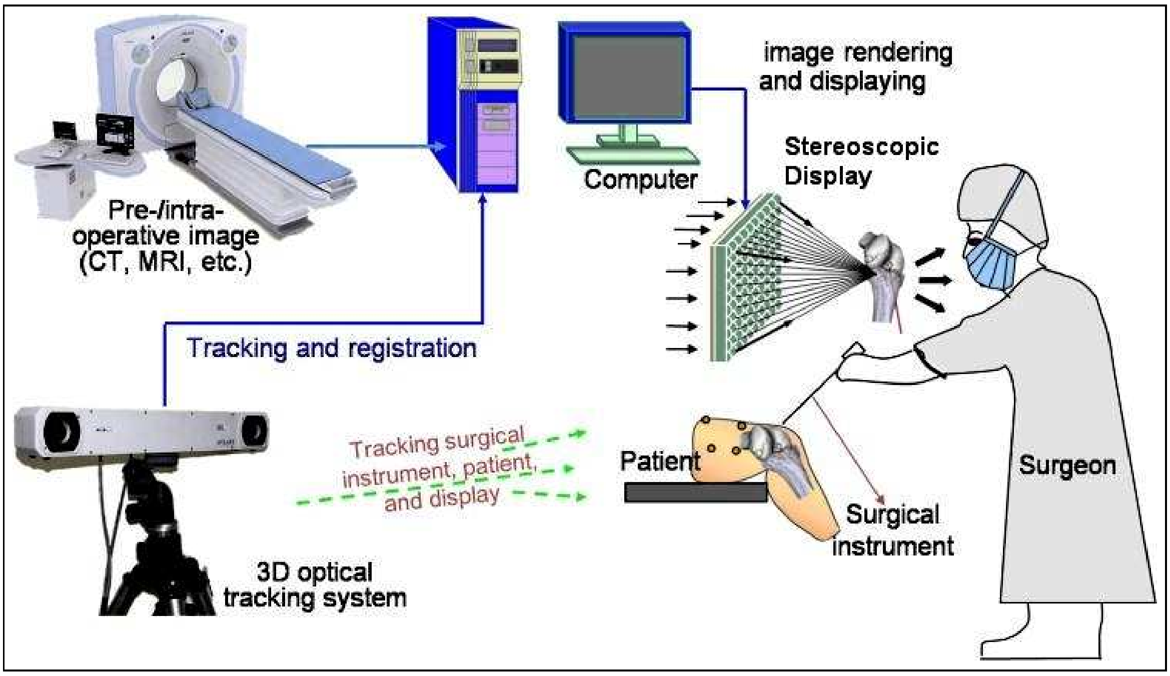


Figure 1.1 Stereoscopic display in surgical navigation

recently [3]. This thesis focuses on using autostereoscopic displays in a CAS system for providing augmented reality so that surgeons can see appropriately prepared images with 3D depth. The system was formed using the functionalities of an open-source application called Slicer [4].

Figure 1.1 illustrates an example of using a stereoscopic display in surgical navigation [2]. Pre-operative images are processed by a computer and displayed on the display. Also intra-operative images and medical device orientation data provided by tracking devices are sent to the computer during surgery. Registration of intra and pre-operative images is done and 3D rendered images are viewed on the stereoscopic display.

1.2 Roadmap

Chapter 2 begins with overview of computer assisted surgery. Then Slicer and stereoscopic displays are introduced and some studies on using stereoscopic displays in computer assisted surgery are reviewed. Chapter 3 describes the proposed system. Chapter 4 gives the results. 5 discusses the results and offers some future work. Appendix A is the specifications of the stereoscopic display used in the study.

2. BACKGROUND

In this chapter, computer assisted surgery, Slicer software and stereoscopic displays will be covered in detail. At last section, some of the research literature related to autostereoscopy in surgery will be presented briefly.

2.1 Computer Assisted Surgery

Computer Assisted Surgery (CAS) represents a surgical concept and set of methods, that use computer technology for presurgical planning, and for guiding or performing surgical interventions. CAS is also known as computer aided surgery, computer assisted intervention, image guided surgery and surgical navigation. CAS has been a leading factor for the development of robotic surgery [5]. General principles of CAS include:

- Making a virtual image of the patient: The most important component for CAS is the development of an accurate model of the patient. This can be conducted through a number of medical imaging technologies including CT, MRI, X-Rays, Ultrasound plus many more. For the generation of this model, the anatomical region to be operated has to be scanned and uploaded into the computer system. It is possible to employ a number of scanning methods, with the datasets combined through data fusion techniques. The final objective is the making of a 3D dataset that reproduces the exact geometrical situation of the normal and pathological tissues and structures of that region. The contrasts of the 3D dataset (with its tens of millions of pixels) provide the detail of soft and hard tissue structures, and thus allow a computer to differentiate, and visually separate for a human, the different tissues and structures. The image data taken from a patient will often include intentional landmark features, in order to be able to later realign the virtual dataset against the actual patient during surgery [5].

- Image analysis and processing: Image analysis involves the manipulation of the patients 3D model to extract relevant information from the data. Using the differing contrast levels of the different tissues within the imagery, as examples, a model can be changed to show just hard structures such as bone, or view the flow of arteries and veins through the brain.

- Diagnostic, preoperative planning, surgical simulation: Using specialized software the gathered dataset can be rendered as a virtual 3D model of the patient, this model can be easily manipulated by a surgeon to provide views from any angle and at any depth within the volume. Thus the surgeon can better assess the case and establish a more accurate diagnostic. Furthermore, the surgical intervention will be planned and simulated virtually, before actual surgery takes place. Using dedicated software, the surgical robot will be programmed to carry out the pre-planned actions during the actual surgical intervention.

- Surgical navigation: In CAS, the actual intervention is defined as surgical navigation. This consists of the correlated actions of the surgeon and the surgical robot which has been programmed to carry out certain actions during the preoperative planning procedure.

CAS starts with the premise of a much better visualization of the operative field, thus allowing a more accurate preoperative diagnostic and a well defined surgical planning, by using surgical planning in a preoperative virtual environment. This way, the surgeon can easily assess most of the surgical difficulties and risks and have a clear idea about how to optimize the surgical approach and decrease surgical morbidity. During the operation, the computer guidance improves the geometrical accuracy of the surgical gestures and also reduce the redundancy of the surgeon's acts. This significantly improves ergonomy in the operating room, decreases the risk of surgical errors and reduces the operating time [5].

Many CAS systems have been developed by different universities and research institutes. Currently, commercially available and notable systems approved for a clinical use are mainly StealthStation [6] and DigiPointeur [7]. DigiPointeur use an electromagnetically tracking system while StealthStation provides both optical and electromagnetic tracking systems. Osirix [8] is an open-source image processing software dedicated to medical images. It works under Mac Os X only. It offers FDA certified version but it is not open-source.

2.2 Slicer

Slicer [4], or 3D Slicer, is a free, open source software package for visualization and image analysis. It is natively designed to be available on multiple platforms, including Windows, Linux and Mac Os X. The executables and source code are available under free open source licensing agreement under which there are no reciprocity requirements, no restrictions on use, and no guarantees of performance. It leverages a variety of toolkits and software methodologies that have been labeled the NA-MIC [9] kit.

Slicer consists of more than over a million lines of code, mostly C++. It is a multi-institution effort to share the latest advances in image analysis with the scientific and clinical community. This massive software development effort has been enabled by the participation of several large scale NIH funded efforts. The funding support comes from several federal US funding sources [10].

History: Slicer was initiated as a masters thesis project between the Surgical Planning Laboratory at the Brigham and Women's Hospital and the MIT Artificial Intelligence Laboratory in 1998. It has been downloaded many thousand times. A variety of publications were enabled by the software. A new, completely rearchitected version of Slicer was developed and has been released in 2007. In May of 2008 version 3.2, in May of 2009 version 3.4 and in June of 2010 version 3.6 of Slicer has been released [10].

Slicer continues to be a research package and is not intended for clinical use. Testing of functionality is an ongoing activity with high priority, however, some features of it are not fully tested.

2.2.1 Slicer Goals and Non-Goals

To make a system meeting those requirements, Slicer was designed and continues to evolve with several goals and "non-goals" in mind. The term "non-goals" is used to refer to considerations that may be driving factors for other software development efforts but have been explicitly excluded from Slicer's objectives [1].

Slicer goals:

- To establish a common development platform for researchers within a clinical research environment;
- To provide users with a familiar user interface to perform image processing and visualization tasks;
- To establish a set of conventions for data handling and exchange that both developers and users can adopt when there is no overriding reason not to do so;
- To encourage transfer of algorithm and visualization techniques from developers to users for evaluation, refinement, and use;
- To foster information exchange and collaboration between different researchers, departments, and institutions, locally and world-wide;
- To minimize the different costs of entry and membership in the developer and user community.

Slicer "non-goals":

- Not a goal to make a self-supporting revenue stream based on software sales or support;

- Not a goal to further sales of a required commercial software package or hardware device;
- Not a goal to lock users or developers into a single software platform;
- Not a goal to protect intellectual property by limiting access to software code or internal functionality;
- Not a goal to contractually guarantee clinical accuracy or reliability for research code;
- Not a goal to have the code FDA approved;
- Not a goal to provide all software components written internally "from scratch" in their entirety.

Slicer's "non-goals" may well be valid, even necessary goals for a commercial software company. It is also possible that a commercial third-party might use Slicer or parts of the Slicer code to help meet different goals [1].

2.2.2 Medical Reality Modeling Language

Visualizing medical data involves combining various data sets into a single scene, and exploring the scene interactively. The usage of Slicer typically involves the making of a scene from a variety of volume data sets, surface models derived from those volumes, and transformations derived from 3D registrations of both the volumes and models. Developers of Slicer found that the proper coordination of these items is easiest to obtain by the use of a hierarchical modeling paradigm as exemplified by the modeling systems and languages of graphics and CAD/CAM [11].

Toward this end, developers made a novel file format for expressing 3D scenes composed of volumes, surface models, and the coordinate transforms between them. The Medical Reality Modeling Language (MRML) presents a format for describing scenes that consist of various types of data sets collected in various geometric locations. MRML files are not a copy of the data in another format. Instead, a MRML file describes where the data is stored so the data can remain in its original format and location. Second, a MRML file describes how to position the data sets relative to each other in 3D space. Third, a MRML file describes how to display the data by specifying parameters for rendering and coloring [12]. More documentation about the syntax is available in the guide named MRMLaid [13].

MRML is implemented as a type of XML document where new tags have been defined to handle medical data types such as volumes, models, and the coordinate transforms between them. There are several advantages to building on the XML standard, as opposed to an original format. The World Wide Web has popularized markup languages so that the XML structure is immediately familiar to computer scientists. An application programming interface (API) allows programs to parse and write MRML files.

2.2.3 NRRD File Format

NRRD is a library and file format designed to support scientific visualization and image processing involving N-dimensional raster data. NRRD stands for "nearly raw raster data". Besides dimensional generality, NRRD is flexible with respect to type (8 integral types, 2 floating point types), encoding of written files (raw, ascii, hex, or gzip or bzip2 compression), and endianness (the byte order of data is explicitly recorded when the type or encoding expose it). Besides the NRRD format, the library can read and write PNG, PPM, and PGM images, as well as some VTK "STRUCTURED POINTS" datasets. About two dozen operations on raster data are implemented, including simple things like quantizing, slicing, and cropping, as well as fancier things like projection, histogram equalization, and filtered resampling (up and down) with arbitrary separable kernels [14].

Slicer can read NRRD files and can convert DICOM files to NRRD. Converting

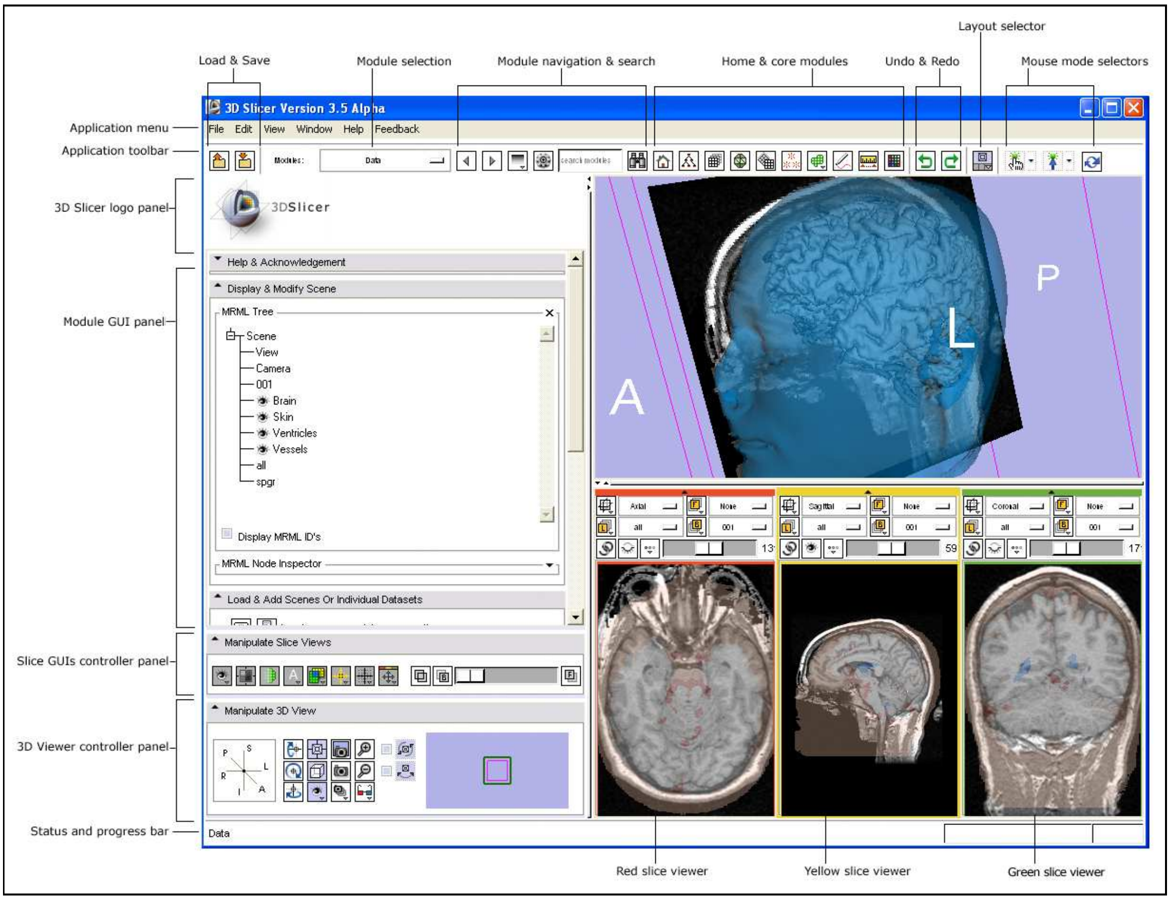


Figure 2.1 Slicer main application GUI

DICOM to NRRD is very useful because many files in DICOM series become one NRRD file. Also the output may be encoded using gzip compression leading less disk usage.

2.2.4 Application GUI and Data Handling

Slicer's main desktop interface provides top-level access to most commonly-used features, and organizes them into logical groupings. These groups of features are presented in a number of interface panels on the GUI. The interface is designed to be easy to learn and remember, to ease navigation of Slicer's large functionality, and to easily collapse and hide when one does not need to see it. Figure 2.1 is the schematic of the main application GUI [15].

Slicer can read and write many formats. These formats include:

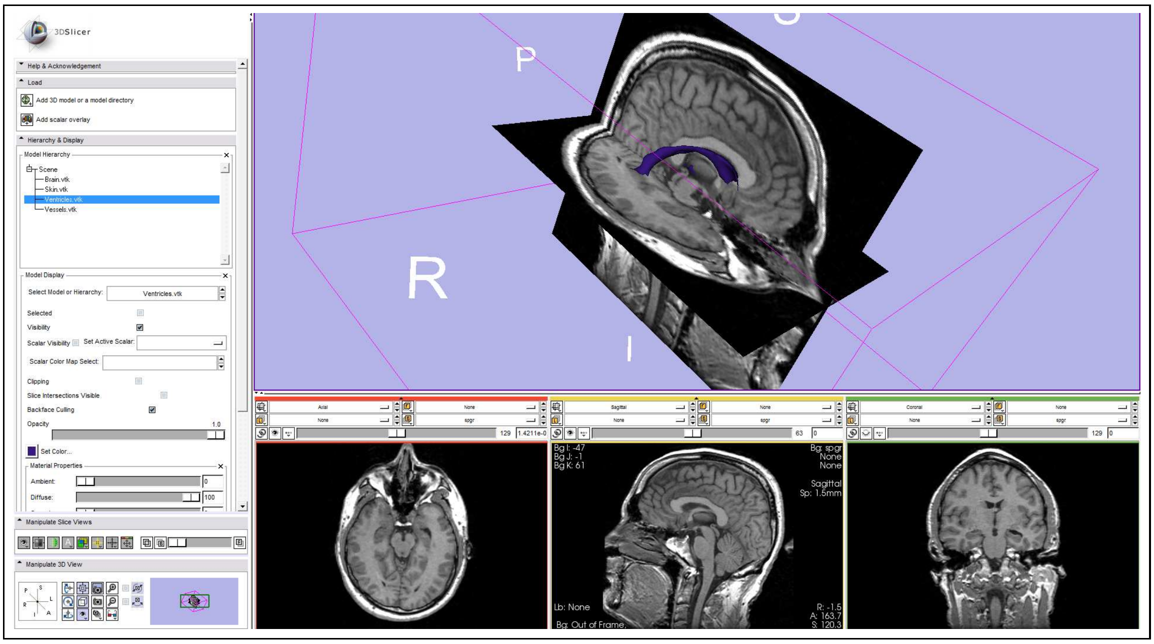
- Volumes: NRRD, MetaImage, VTK, Analyze, BMP, BioRad, Brains2, GIPL, JPEG, LSM, NifTI, PNG, Stimulate, TIFF;
- Models: Poly Data (.vtk), XML Poly Data, STL;
- Fiducials: Fiducial List CSV (.fcsv), Text;
- Transforms: Transform (.tfm), Text.

For data loading and saving, File menu is used. All files in the scene can be observed using the Data module. It is possible to capture snapshots of current scene and restore them later. Scene snapshots are a convenience tool for organizing multiple "live views" of the data in the scene. One can make any number of snapshots and control parameters such as the 3D view, model visibility, window layout, and other parameters. This can be used to set up a series of predefined starting points for looking at portions of the data in detail. For example, one may have one overview scene which shows an external view of the body along with interior views with the skin surface turned off and slice planes visible to highlight a tumor location.

Slicer displays models at the 3D Viewer, and slices of the images (ex. MRI) at the 2D Slice Viewer (Figure 2.2). Many operations like zooming in and out, rolling, pitching, yawing can be done on models. Slice viewer controllers let user browse through the slices and show or hide slices at the 3D Viewer. Each model can be modified separately using Models module where opacity, visibility, color, etc. of each model can be changed (Figure 2.3).

2.2.5 Modularity

One of the most important principles of Slicer is modularity. Modular systems allow developers working in relative isolation to produce elements of value that other



Select Model or Hierarchy: Ventricles.vtk

Selected ☐

Visibility ☑

Scalar Visibility ☐ Set Active Scalar:

Scalar Color Map Select:

Clipping ☐

Slice Intersections Visible ☐

Backface Culling ☑

Opacity 1.0

Ambient: 0

Diffuse: 100

Bg I: -47
Bg J: -1
Bg K: 61

Bg: spgr
None
None

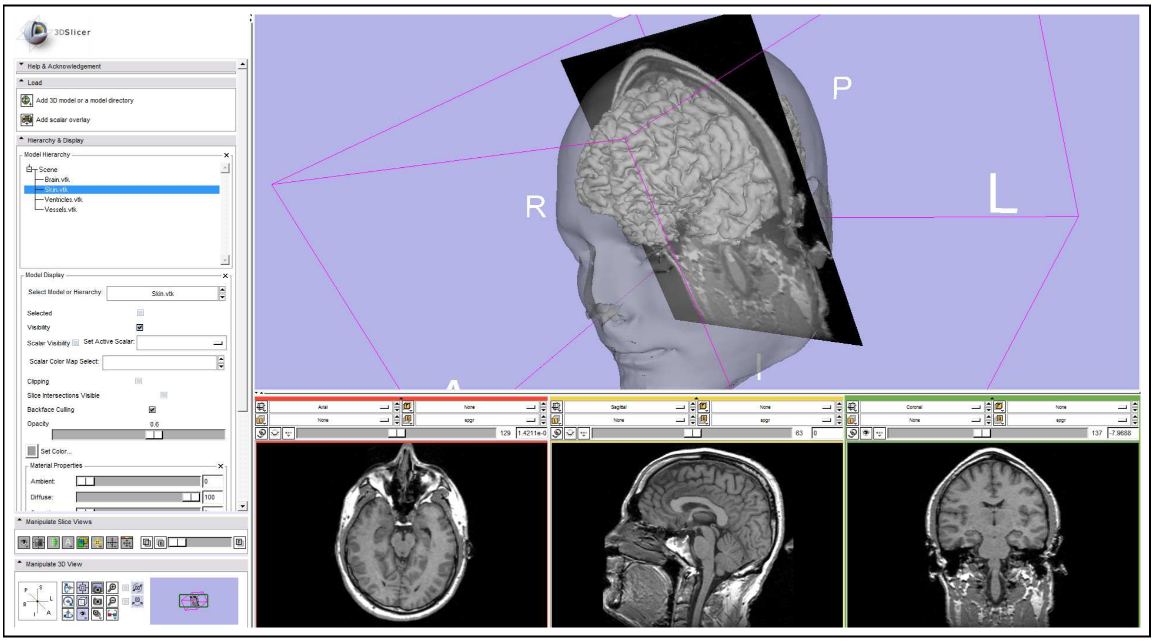
Sagittal
Sp: 1.5mm

Lb: None

Bg: Out of Frame.

R: -1.5
A: 163.7
S: 120.3

Figure 2.2 Visualization of models and slices



Select Model or Hierarchy: Skin.vtk

Selected ☐

Visibility ☑

Scalar Visibility ☐ Set Active Scalar:

Scalar Color Map Select:

Clipping ☐

Slice Intersections Visible ☐

Backface Culling ☑

Opacity 0.6

Ambient: 0

Diffuse: 100

Figure 2.3 Customized models

people can use. Modularity is also essential for software stability in quickly developing systems: a small change by any one developer should have minimal or no adverse impact on other developers or users. Modularity encourages the concept of a toolbox that can be tailored to particular tasks. Finally, modular systems allow developers to concentrate on their own areas of expertise, enabling them to understand, implement and test their own software elements without extensive knowledge of the larger platform.

2.3 Stereoscopic Displays

Most of the perceptual cues that humans use to visualize the world's 3D structure are available in 2D projections. This is why we can make sense of photographs and images on a television screen, at the cinema, or on a computer monitor. Such cues include occlusion (one object partially covering another), perspective (point of view), familiar size (we know the real-world sizes of many objects), and atmospheric haze (objects further away look more washed out) [3].

Four cues are missing from 2D media:

1. Stereo parallax: Seeing a different image with each eye;
2. Movement parallax: Seeing different images when the head is moved;
3. Accommodation: The eyes' lenses focus on the object of interest;
4. Convergence: Both eyes converge on the object of interest.

All 3D display technologies (stereoscopic displays) provide at least stereo parallax. They work by making at least two images of each scene, one image of the scene as a person's left eye would see it, and the other as a person's right eye would see it. These two images are called a stereo pair. The imaging system must cause the left eye to see only the left eye image, and the right eye to see only the right eye image [3].

2.3.1 3D With Glasses or Headsets

The well-known 3D displays that require the viewer to wear special glasses present two different images in the same display plane. The glasses select which of the two images is visible to each of the viewer's eyes. Technologies for achieving this include:

- A standard color display combined with colored glasses (the anaglyph method);
- Two standard displays, made coplanar by a half-silvered mirror, combined with polarized glasses;
- Two projectors, projecting onto a polarity-pre-serving screen, combined with polarized glasses;
- A double-frame rate display combined with shuttered glasses.

An alternative to glasses is to mount two small displays in a headset-one display for each eye. Today's technology makes such devices lightweight. These devices have a range of applications but are limited by the need to wear the headset and the isolation from the real world caused by being able to see only the head-mounted display. See-through headsets are available, but the display is then always seen against the background of the real world, again limiting their applicability [3].

2.3.2 Autostereoscopic Displays

Autostereoscopic displays provide 3D perception without the need for special glasses or other headgear. There are three rather arbitrarily categorized types of autostereoscopic displays [3]:

1. Two-view displays;

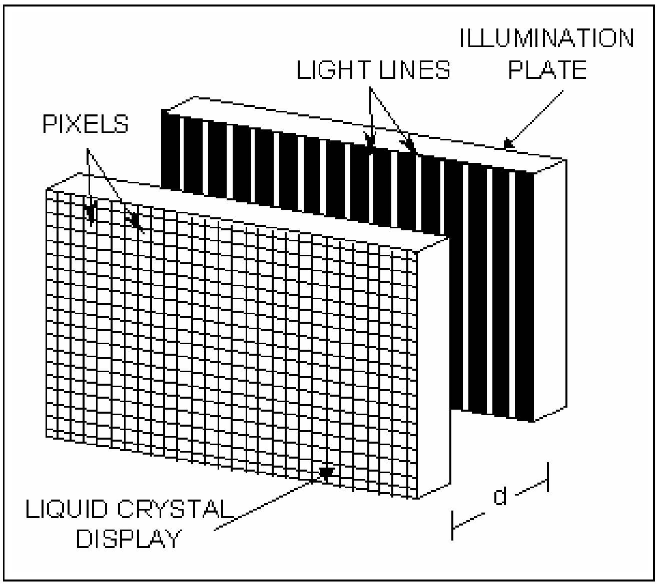


Figure 2.4 DTI display structure

2. Head-tracked displays, normally two-view;

3. Multiview displays, with three or more views.

2.3.2.1 DTI Virtual Window 19. We used DTI Virtual Window 19 display in our study. DTI [16] Virtual Window 19 is a multiview autostereoscopic display. The specifications of the display can be found in Table A.1. With the DTI display, stereo displaying is accomplished with a special illumination pattern and optics behind the LCD screen which make alternate columns of pixels visible to the left and right eyes when one is sitting in front of the display, or in certain areas off to the side [17].

As illustrated in Figures 2.4 and 2.5, the DTI displays left and right halves of stereo pairs on alternate columns of pixels on the LCD. The left image appears on the odd numbered columns and the right image appears on the even numbered columns. For example, if an LCD is used that has 1024 columns and 768 rows of pixels, each complete stereoscopic image consists of 512 columns and 768 rows.

Both halves of a stereo pair are displayed simultaneously and directed to corresponding eyes. This is accomplished with a special illumination plate located behind

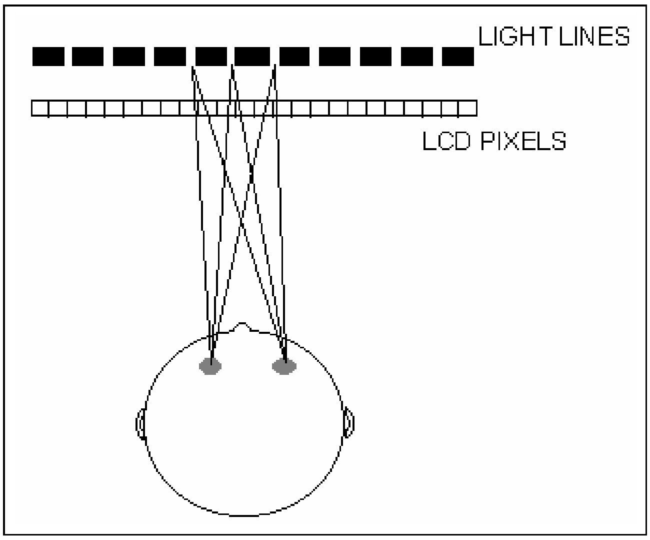


Figure 2.5 Generation of stereoscopic image

the LCD. Using light from compact, intense light sources, the illumination plate optically generates a lattice of very thin, very bright, uniformly spaced vertical light lines, in this case 512 of them.

The lines are precisely spaced with respect to the pixel columns of the LCD. Because of the parallax inherent in our binocular vision, the left eye sees all of these lines through the odd columns of the LCD, while the right eye sees them through the even columns. The left eye sees only the left eye portion of the stereo pair, while the right eye sees only the right eye portion. This enables the observer to perceive the image in three dimensions. This arrangement, exclusive to DTI, is called Parallax Illumination.

There is a fixed relation between *d* (Figure 2.4), the distance between the LCD and the illumination plate, and the distance between the observer's face and the LCD screen, the viewing distance. This distance in part determines the dimensions and positions of the "viewing zones" depicted in Figure 2.6. These viewing zones are the regions in front of the display where the observer can perceive the left and right eye images. Stereoscopic images can be seen from any position where one's left eye is in a left eye zone and one's right eye is in a right eye zone.

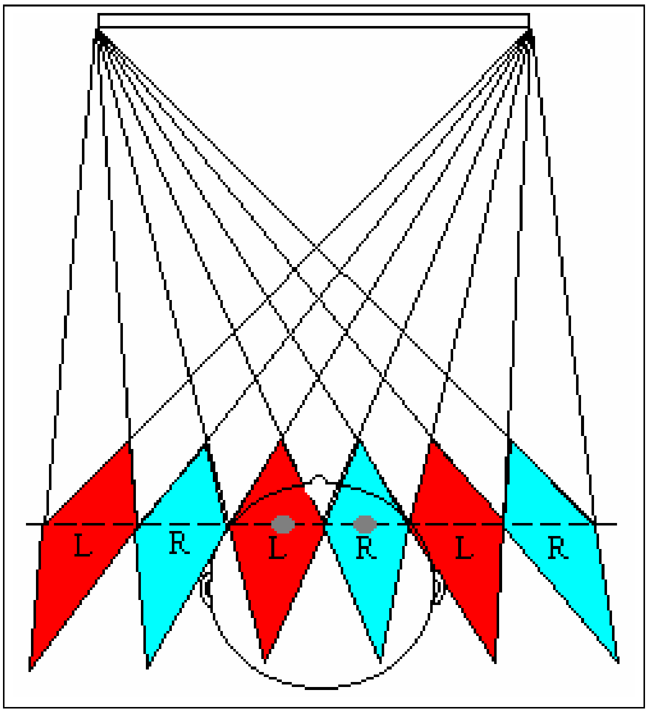


Figure 2.6 DTI display viewing zones

When the halves of the stereo pair are made to correspond to the scene perspective that would naturally be seen by the respective eyes, a vivid illusion of three-dimensionality is created. The objects seem to come out of the screen, giving the impression of an open window through which objects can protrude or retreat into the background [17].

In addition, the Parallax Illumination system is designed so that it can generate in the same display at a flick of a switch both stereoscopic and non-stereoscopic images, the latter at double the resolution. This ability to instantly switch from 3D to 2D makes the DTI monitor unique in the world. No other 3D flat panel display can provide full resolution 2D images. This allows the DTI display to become the primary desktop display, since it can be used for both 2D and 3D images with the push of a button.

Although DTI 3D displays are designed to be used by one person at a time, this technology does allow several people to view stereo at the same time. Note that the areas where left and right eye views are seen repeat to the left and right of center. One can see 3D from any position where the left eye is in a left eye zone and the right eye is in right eye zone. Additionally, there is little effective vertical restriction. The 3D effect is readily seen whether sitting directly in front of the display or standing behind the person sitting in front of it [17].

2.3.3 Current Application Areas

Some of the application areas of stereoscopic displays include [18]:

- **Data Visualization:** Protein, DNA and molecular modeling, stereo microscopy, weather forecasting, wind tunnel work (aerodynamics), aerial photography (photogrammetry), financial modeling/forecasting, CAD/CAM/design engineering, process control/modeling, telerobotics;
- **Medical:** Endoscopy, ophthalmology, body imaging (MRI, CT, etc.), surgical simulation/training, surgical imaging;
- **Architecture:** Design, walk-throughs, landscaping, interior design, human factors;
- **Entertainment:** Computer game play, computer game design, animation;
- **Military:** Simulation/training, heads-up displays, reconnaissance, satellite imagery analysis, cockpit/control displays;
- **Business and Industry:** 3D video conferencing, financial modeling/accounting, process control/work flow modeling, presentations, trade shows, kiosks/retailing, conference room/reception lobby presentations, manipulation of hazardous materials, small part assembly, industrial inspection;
- **Real Estate:** Long distance sales presentations, commercial or residential real estate walk-throughs/walk-arounds.

2.3.4 Slicer Stereo Modes

Slicer has the capability to display data at the 3D Viewer stereoscopically in a number of fashions including [19]:

- Red/Blue: For use with red/blue glasses commonly available in magazines or on the internet. The scene is drawn twice (once in each color from the location of each eye). Using the glasses separates the views and remakes perspective. There is some "bleed-through" of the images to the opposite eye, but users can generally see depth using this algorithm. The drawback to this algorithm is the natural color of objects is lost due to the red and blue only rendering.
- Analglyph: This algorithm uses the same glasses as the red/blue algorithm but preserves much of the natural color of rendered objects. In general, this preserves the colors in the rendered scene, but adds depth. Some "bleed-through" still occurs between the eyes, but there are less visual artifacts compared with the red/blue algorithm.
- Interlaced: In this algorithm the pixel lines from each eye are intermixed as the picture is rendered from top to bottom. With an ordinary monitor the lines will seem "jaggy" because we are observing the left and right eye's version of the scene superimposed. However, a stereo image results when interlaced signals are fed to a specially-configured stereo monitor or stereo display panel.
- CrystalEyes: This stereo mode is named after the famous, legacy glasses sold by RealD [20]. This mode is also sometimes called "active stereo" or "frame sequential stereo". In this mode, successive video frames alternate between the left and right eyes as time progresses. A pair of special goggles or a special display route the signals to one eye or the other in quick succession. As long as the frame rate is fast enough so the user does not see excessive flicker, this is a convincing rendering approach. However, this algorithm makes the most demands on the computing and display systems of all stereo options. Only some GPUs can produce active stereo, as support for OpenGL [21] quad-buffered stereo

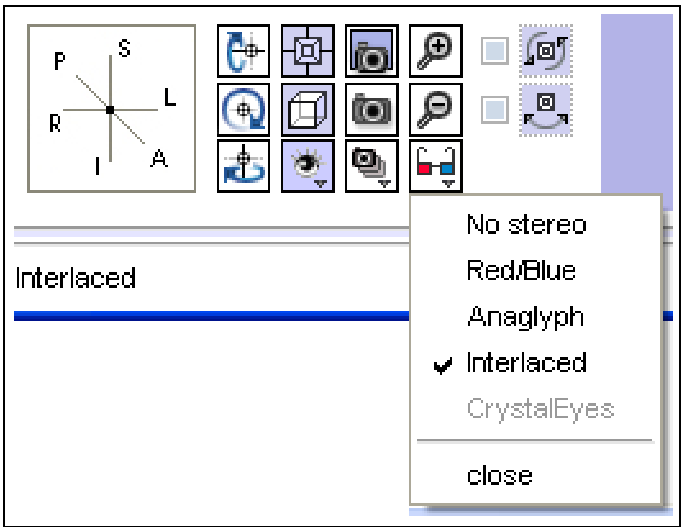


Figure 2.7 Stereo modes on Slicer GUI

mode is required. The display device (panel, projector, LCD, etc.) attached to the workstation must also be able to handle frame sequential stereo modes as well. Not all display devices support this rendering mode.

The first two algorithms require only 3D glasses, not any special computer hardware configurations. The last two algorithms require special stereo-ready display systems. Also invoking Slicer from the command line and using the "–stereo" option is required for CrystalEyes mode. This option instructs Slicer to configure a window using OpenGL Quad-buffered stereo. Figure 2.7 shows the stereo modes in 3D Viewer Controls.

2.4 Related Work

Stereoscopic imaging is a popular application and there have been several studies on using stereoscopy in computer assisted surgery. Liao et. al. [22] used an integral videography autostereoscopic display in cardiac surgery guidance system. They also used Slicer for data analysis and visualization. Their study can superimpose the real, intuitive 3D image for cardiac diagnosis and surgical guidance. In a more recent study they used integral videography autostereoscopic image overlay for augmented reality

[23]. Their 3D surgical navigation system can superimpose a real and intuitive 3D image onto a patient's body for accurate and less-invasive surgery.

Abildgaard et. al. [24] showed that identification of individual intracranial arterial segments visualized in 3D models from MR angiography is improved with the use of an autosteroscopic display. Schlaefer et. al. [25] used an autostereoscopic display in radiosurgery for identification of efficient treatment beams. Their study proved that stereoscopic visualization was useful in the analysis and guidance of beam placement.

3. METHOD

Computer assisted surgery systems are widely used to help surgeons since they let making a virtual image of the patient, image analysis, preoperative planning and surgical navigation as described in Chapter 2. Most systems use conventional 2D displays to view the images and models resulting decreased apprehension of the structures and their localization.

In this study, it is aimed to use an autostereoscopic display for viewing images and models of the structures of interest (ex. tumors) in a computer assisted surgery system so as to provide surgeons image depth information during surgical planning and guidance. The aim of surgical planning is determining the best surgical approach by integrating image information from multiple sources and highlighting structures of interest.

Integrating image information from multiple sources is achieved by *registration*. Highlighting structures of interest is achieved by *segmentation* and *making models* of the structures. During surgery, *navigation* is used while applying the determined approach. These are some common functions of a CAS system. Also most CAS systems have stereo modes for appropriate tools or devices. In this study Slicer is used to form a basic CAS system as it has all necessary tools.

3.1 Registration

The goal of the registration is to bring two or more images into alignment such that corresponding content (anatomy, structure) appears in the same location an orientation when viewed together. Because the image is a digital representation, registration involves a reformatting of the stored image data. The common practice is to leave one image as is and reformat the other in the orientation of the first. It

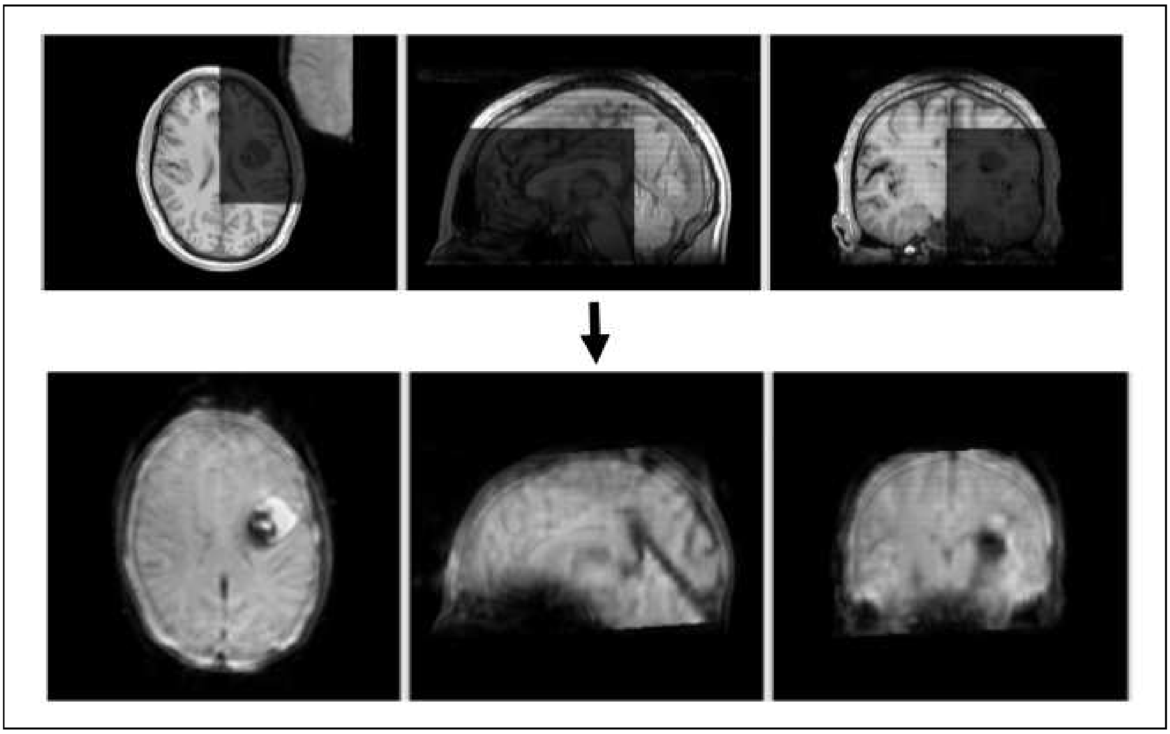


Figure 3.1 Registration of anatomical MRI and functional MRI

can be thought as a re-scan of the subject, along the same orientation as the reference image. When the display of one image is manually adjusted such that both images roughly show the same location, a type of registration is performed. Figure 3.1 shows registration of anatomical MRI and functional MRI of a brain. After registration the volumes overlap.

Because most medical images are 3-dimensional, there are complex ways in which the two images can differ in orientation. For the brain example, there are relative shifts in any of 3 directions and 3 possible rotations (yaw, pitch and roll). This means as many as 6 parameters must be adjusted to register the two images. The software we used offers both manual and automated ways to do this task. For manual registration Transform module is used. The moving image is moved under the transform and the orientation parameters are set. Then the transform may be hardened to the moving image. Manual registration is usually used as an initial transform for automated registrations. There are several automated registration modules. Automated techniques estimate the rotation, translation, scale and shear needed to align the moving image with the fixed image. Automated registration modules have some common parameters including initial transform, output transform, fixed image, moving image, and output volume. Parameter definitions and module usage information can be found on regarding module tutorials [26].

3.2 Segmentation and Model Making

Models let surgeons view the structure as a complete unit instead of viewing it slice by slice and perform measurements, such as volume measurements, which can be difficult to perform on the image volume itself.

In order to make a model, the structure should be segmented. The software we used offers several modules for automated or semi-automated segmentation. Parameter definitions and module usage information can be found on regarding module tutorials [27].

3.3 Stereo Displaying

Stereo viewing helps surgeons at surgical planning and guidance [24]. As described in Section 2.3.4 the software has several stereo modes. The desired stereo mode can be enabled using the stereo option at "3D Viewer Controls" at application GUI (Figure 2.7). In our system, the steps of stereo displaying are:

- Selecting appropriate stereo mode on driver GUI;
- Selecting appropriate stereo mode on the software;
- Using the control application of the display and activating stereo.

3.4 Navigation

In surgical guidance, navigation is used for determining the positions and orientations of surgical tools using a tracking system and displaying virtual representations of those tools on the screen for the surgeon. Some clinical uses for navigation are:

- Real-time update of tool position and orientation in augmented reality environments (ex. for minimally-invasive cardiac surgery);
- Image-to-patient registration using tracked pointer tools (ex. for total hip replacement surgery);
- Image-to-patient registration using tracked intraoperative imaging devices (ex. ultrasound).

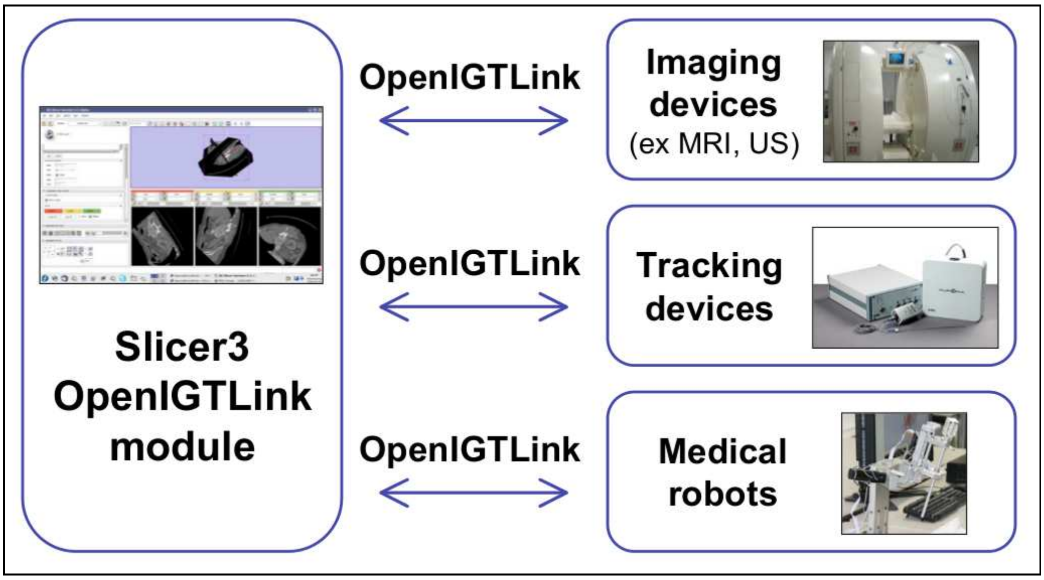


Figure 3.2 Slicer OpenIGTLink module

In order to perform navigation, software must be able to receive position and orientation data from tracking devices. The software we used can interface with medical devices, such as tracking devices, imaging devices and medical robots using OpenIGTLink. OpenIGTLink is a communication protocol that allows communication with external devices (Figure 3.2). The OpenIGTLink protocol specifies the structure of the messages sent between the client and the server.

Connections to the devices can be set using OpenIGTLink module. When a connection is added using the module a transform node is added to the Data module. This transform can be viewed using Transforms module. Using the OpenIGTLink module it is possible to show or hide locator model. The transform can be applied to the models so that they move according to the transforms from the tracker. For moving slices according to the tracker, the drivers under the "Visualization/Slice Control" pane can be activated. Thus the image origin is set to the locator's position.

4. RESULTS

The main goal of the proposed study was to perform common tasks of a computer assisted surgery system and integrate an autostereoscopic display to the system. We used Slicer for core functionalities of a CAS system and performing tasks on an example case data derived from community [28]. We built the model of the structure of interest (tumor) after registration and segmentation of the images. After that we drove the autostereoscopic display and viewed the model in stereo mode. We also performed basic navigation using a tracking simulator.

Example Case: The image data consisted of SPGR [29] MRI (anatomical MRI) and functional MRI (both motor and language). Language fMRI was statistically pre-processed using SPM [30].

Clinical Background: Imaging showed a large lesion in the left frontal region of the brain, predicted to be a glioma (brain tumor originating from glial cells). Also fMRI showed some speech areas were close to the lesion.

4.1 Registration

In the case, we used the anatomical MRI and functional MRI image volumes of the patient. The fMRI lets surgeons identify regions of the brain important for language or movement. Possible damage to these regions can result in problems with speech, reading or movement. The image volumes were not aligned so they were not suitable for surgical planning when viewed together.

We set SPGR MRI as fixed image and fMRI as moving image. Using Transforms module, we adjusted orientation parameters of fMRI so that it overlapped MRI. Figure shows the result of the registration.

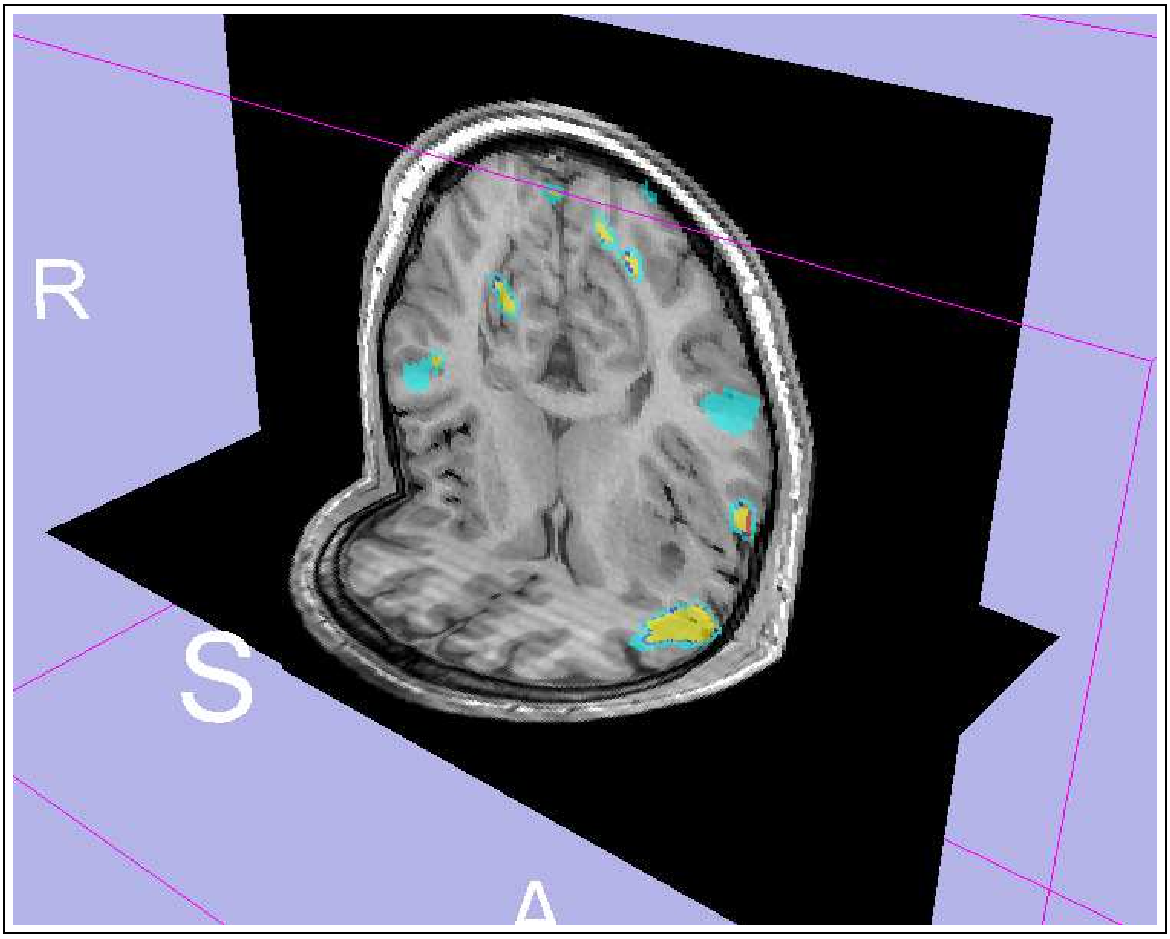


Figure 4.1 Registered SPGR MRI and fMRI

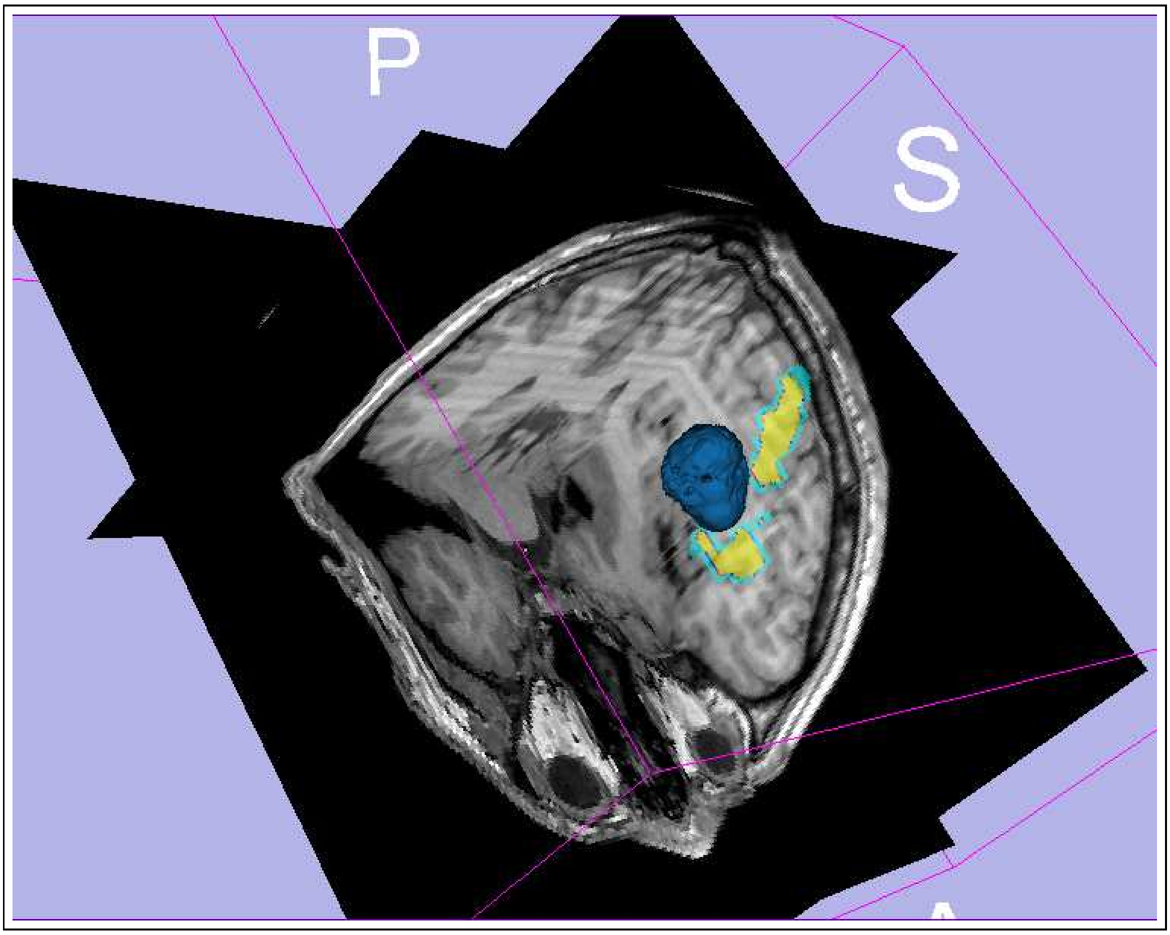


Figure 4.2 Tumor Model

4.2 Segmentation and Model Making

We used Editor module and segmented the tumor using "Threshold" and "Save Island" tools. Model was built using "Model Maker" tool. Figure 4.2 shows the reconstructed tumor model over MRI and fMRI. Yellow areas represent speech areas in the figure. Model information was:

- Surface Area: 4040.4 mm^2;
- Volume: 11135 mm^3.

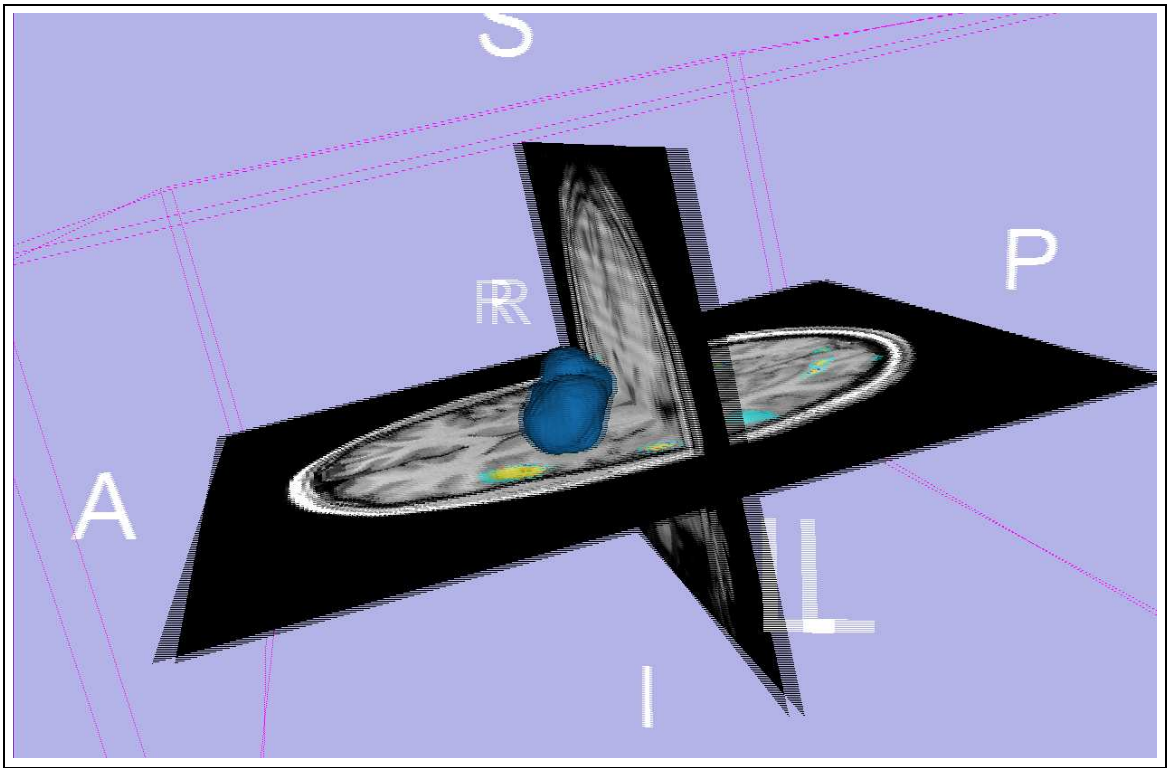
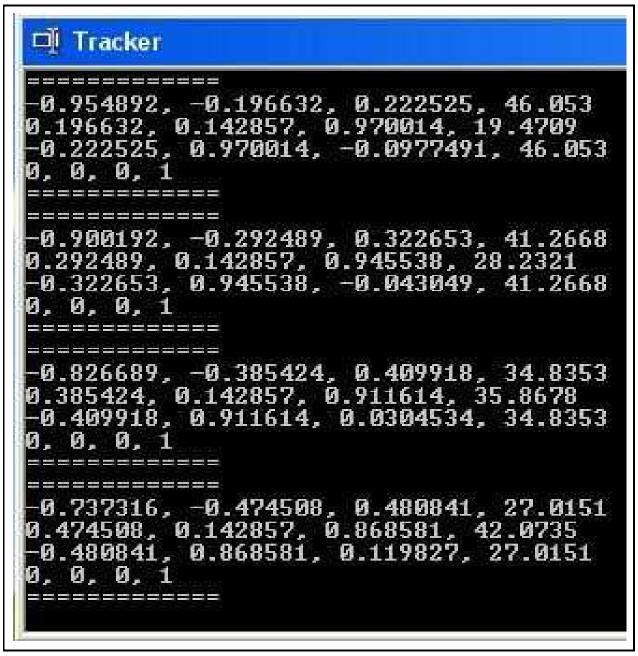


Figure 4.3 The tumor model in interlaced stereo mode

4.3 Stereo Displaying

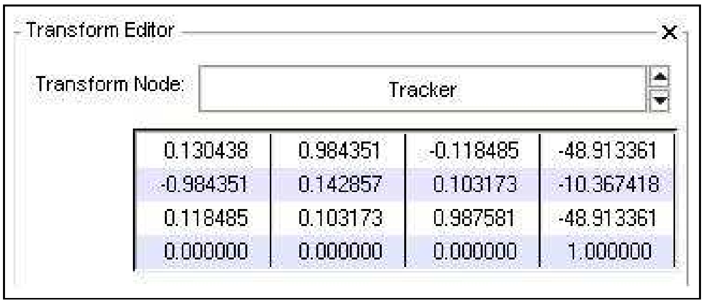
We tested our autostereoscopic display and found that it supported interlaced mode. Also we realized that we need a stereoscopic driver to activate the display's 3D mode and view the stereo image on the display. We have used iZ3D Driver [31] as it supported interlaced mode.

In our case, we activated stereo and viewed the reconstructed tumor model in depth resulting better apprehension of the structure and its location. Figure 4.3 shows the stereo image of the tumor model in interlaced mode.



```
=============
-0.954892, -0.196632, 0.222525, 46.053
0.196632, 0.142857, 0.970014, 19.4709
-0.222525, 0.970014, -0.0977491, 46.053
0, 0, 0, 1
=============
=============
-0.900192, -0.292489, 0.322653, 41.2668
0.292489, 0.142857, 0.945538, 28.2321
-0.322653, 0.945538, -0.043049, 41.2668
0, 0, 0, 1
=============
=============
-0.826689, -0.385424, 0.409918, 34.8353
0.385424, 0.142857, 0.911614, 35.8678
-0.409918, 0.911614, 0.0304534, 34.8353
0, 0, 0, 1
=============
=============
-0.737316, -0.474508, 0.480841, 27.0151
0.474508, 0.142857, 0.868581, 42.0735
-0.480841, 0.868581, 0.119827, 27.0151
0, 0, 0, 1
=============
```

Figure 4.4 Tracking Simulator sending transform data



Transform Node: Tracker

0.130438	0.984351	-0.118485	-48.913361
-0.984351	0.142857	0.103173	-10.367418
0.118485	0.103173	0.987581	-48.913361
0.000000	0.000000	0.000000	1.000000

Figure 4.5 Software receiving transform data

4.4 Navigation

We used a tracking simulator since we do not have any tracking device in our laboratory. The tracking simulator acted as the client to send simulated transform data to the software (the server) over OpenIGTLink. After activating the tracker and running the simulator (Figure 4.4) we observed the changing transformation matrix on the Transforms module (Figure 4.5) selecting the tracker transform. Figure 4.6 shows the locator and MRI slices at the 3D viewer.

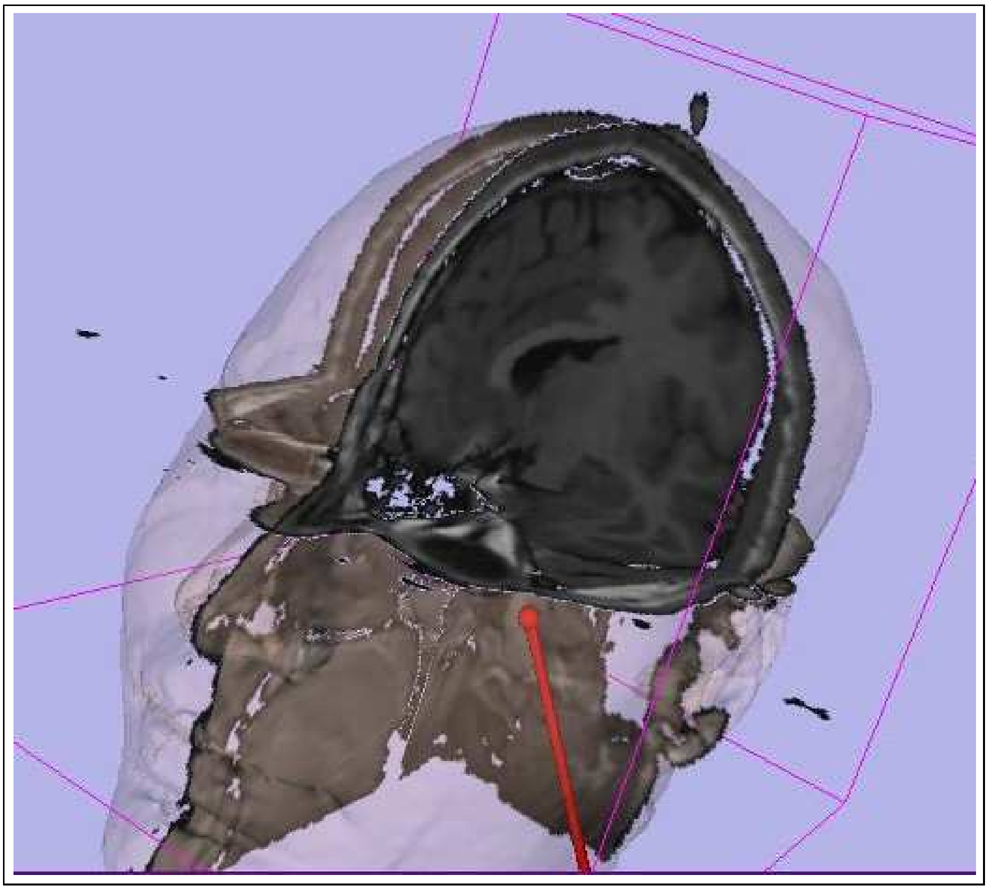


Figure 4.6 Locator at the 3D Viewer

5. CONCLUSION AND FUTURE WORK

Computer assisted surgery is widely used for surgical planning and guidance to improve ergonomy, reduce operating time and decrease the risk of surgical errors. Traditional CAS systems use regular 2D displays to view images, even though images are 3D reconstructed, leading the lack of depth information of the images. This results decreased comprehension and identification of the structures and cuts down the efficiency of the system.

In this study, we proposed an approach addressing the aforementioned problem. We integrated an autostereoscopic display to the system and viewed images in depth.

In order to perform core functionalities of a surgical planning and guidance system, we used Slicer and performed some common tasks including visualization, registration, segmentation and navigation. Slicer is a free open-source software which allows researchers to share algorithms and work within a common framework. It has almost all necessary tools for computer assisted surgery tasks. Also there are many tutorials and examples on large variety of tasks and clinical cases. The learning curve is small and the application GUI is user friendly. It has an active community and it is easy to get help about any issue regarding medical imaging.

Displaying images in true 3D can provide important benefits to the users. One benefit is improved accuracy and reduced errors. Many medical applications strive for nearly perfect accuracy, but current 2D displays hinder this increased user performance. The added depth information in real-depth 3D images allows users to grasp and understand the image much more quickly and accurately. Also viewing images in 3D will help surgeons both prior to the surgery and during the surgery. During surgical planning, surgeons will be able to see reconstructed images (ex. tumors) in depth resulting better apprehension of the structures and their locations in the body. Also during the surgery co-surgeons and assistants will have the opportunity to follow the operation stereoscopically.

The image quality of the display is satisfactory but it is not as good as conventional 2D displays. Further evaluation of the autosteroscopic displays will lead better image qualities. Also stereoscopy is getting more popular. When we reach the point where an autostereoscopic display becomes available that offers the same quality as a conventional display for about the same price, autostereoscopic displays might break out of their niche markets. However, it is unclear whether 3D display will ever become the norm, taking over from 2D in the way that color replaced black-and-white movies and television.

5.1 Future Work

In this study we used image data provided by Slicer community. It may be better to use the system for a number of clinical cases in hospitals. Also we did not present the system to any surgeons nor clinicians. It is important to test the system in a real environment and get feedbacks especially for stereoscopic display's performance and usefulness.

This study does not cover real time stereoscopic displaying, as well. If it is desired then the images captured by video cameras should be side-by-side stereo (2:1 aspect ratio) which is compatible with the display used in the study.

APPENDIX A. DTI VIRTUAL WINDOW 19 SPECIFICATIONS

Table A.1
DTI Virtual Window 19 Specifications.

LCD Panel	Type Display Area Maximum Resolution Pixel pitch Contrast Ratio Display colors Response time Brightness 2D Brightness 3D	19.0" Color TFT LCD 15" horizontal x 12" vertical 1280 x 1024 (SXGA) 0.294 mm 550:1 16.2 million 8 ms 66 FL 23 FL
Inputs	Analog Digital DTI Control	15-pin mini D-Sub DVI-D USB Port Type B
User Controls		2D / 3D reversible left eye / right eye
User Selectable Stereo Formats		Frame Sequential Field Sequential Side-by-Side (2:1 aspect ratio)
Power	Voltage Consumption	AC 110-240 V, 50-60 Hz 40 W (max)
Weight Dimensions (W x H x D)	Gross Physical w/ stand	6.8 kg 422 mm x 410 mm x 168 mm
Included Accessories	AC cable, display cable, USB cable, DTI CD-ROM	

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