Enhancing Reality in the Operating Room

William Lorensen, MS
Harvey Cline, PHD
Christopher Nafis, MS
GE Corporate Research and Development
KW/C215
1 River Road
Schenectady, NY 12345
518-387-6744
lorensen@crd.ge.com

Ron Kikinis, MD
David Altobelli, MD
Langham Gleason, MD
Ferenc Jolesz, MD
Brigham and Womens Hospital
Department of Radiology
75 Francis Street
Boston, MA 02115
617-732-5961
kikinis@bwh.harvard.edu

1: Introduction

Three-dimensional medical imaging provides a non-invasive visualization of human anatomy. These 3D images can supplant the diagnostic information in the 2D cross-sectional images provided by X-ray computed tomography (CT) and magnetic resonance imaging (MRI). The 3D images also enhance communication between the radiologist, who has special training to interpret the CT and MRI images, and the referring physician or surgeon, who are often more comfortable with 3D presentations. This note describes a procedure for surgical planning and surgical support that combines live video of the patient with the computer-generated 3D anatomy of the patient. Prior to surgery, this video mixing permits surgeons to plan access to the pathology that exists within the patient. During an operation, the surgeon can view the live video of the patient's internal anatomy mixed with the 3D computer models.

2: Methods and Materials

Figure 1 shows the steps necessary to create a 3D medical image.

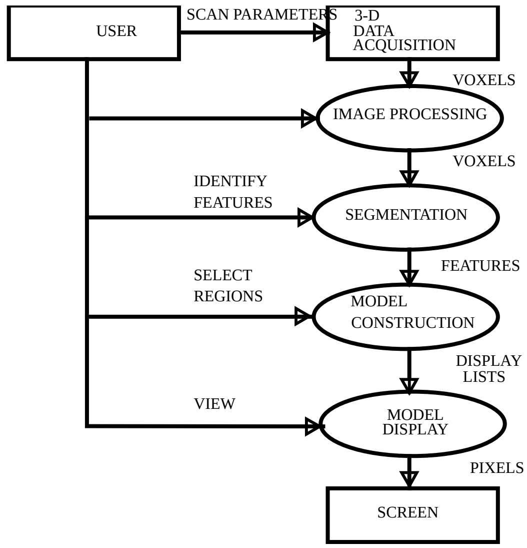

Figure 1. 3D Medical Imaging

Data Acquisition: X-Ray Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are two medical imaging modalities that provide detailed cross-sectional views of the anatomy. Both techniques can acquire multiple contiguous 2D slices to produce a 3D volume that is suitable for subsequent 3D processing.

CT measures the spatially varying X-ray attenuation coefficient. Although CT is particularly well suited to visualize bone structure, injecting contrast material in the blood does enhance soft tissues. MRI images exhibit excellent discrimination of soft tissues. MRI measures the relaxation of nuclear spin magnetization. The contrast mechanism of MRI relies on the spin relaxation times in different tissues. But, this increased contrast on soft tissues poses a challenge to 3D model creation.

Image Processing: Improvements in signal to noise ratios can be achieved by increasing acquisition times or by post processing the acquired images with noise reduction and edge sharpening filters [1].

Tissue Segmentation: Segmentation classifies tissues within the 3D volume. Several approaches are possible and often combinations of these techniques are required to successfully segment the tissues in a volume. Thresholding is the simplest segmentation approach, providing a binary classification of tissues. Connectivity can be used to distinguish between two tissues that have the same contrast but are spatially separated [2]. Multivariate segmentation techniques, use more than one set of images that have different contrast relationships. For MRI, variations in the echo times can produce simultaneous images that are perfectly registered [3].

Model Construction: Following segmentation, surfaces of each tissue are constructed. We have developed two surface generation algorithms: marching cubes [4] and dividing cubes [5]. Marching cubes generates triangles that approximate the isodensity surface of a tissue within a volume. Dividing cubes generates 3D points with surface normals that approximate the surface. The compact point / normal list produced by dividing cubes, lends itself to fast software rendering and even faster custom hardware implementation.

Model Display: Viewing the 3D models requires a suite of display and manipulation tools including flexible virtual camera manipulation and independent object coordinate systems and attributes.

Video Registration: Once the 3D models are created, the rendered images can be combined with live video of the patient. This mixing of computer models and live video brings the surgical plan into the operating room. The schematic in figure 2 shows the setup for the merging of the two video sources. Once aligned, an operator interactively adjusts the mixing of the two video sources. The surgeon looks at a monitor that displays the mixed image. Figure 3 shows example frames from an experiment on a normal volunteer. The video mixer has a variety of options that aid the registration process. Figures 3a and 3b show split windows of computer and patient images. Figure 3d shows the computer generated models of the patient's face and brain. In figure 3d, the surgeon sees the mixed image that contains his hand and pen. Watching this combined image, the surgeon draws outlines of the target and important anatomical details on the patient's head. Figure 3e uses luminance keying to substitute the computer generated image wherever the luminance exceeds a threshold. The final surgical plan is shown in figure 3f with the target drawn as a cross hatched circle.

3: Results

The surgical planning system described above combined with off-the-shelf video equipment comprises an enhanced reality surgical support system. This section describes a recent surgical operation that used the system. The tumor was a frontal glioma. Reference [6] describes the diagnosis, treatment and biology of these infiltrative tumors.

Acquisition: A GE Signa MRI system (GE Medical Systems, Milwaukee, WI) acquired 128 coronal slices, 256 by 256 pixels, 1.5 mm apart. A 24 cm field of view (FOV) produced .9375 mm pixels. The MRI pulse sequence was a spoiled gradient echo with 1 excitation (NEX), repetition / recovery time (TR) of 3500 ms and echo delay (TE) of 500 ms.

Image Processing: The study was filtered to increase the signal to noise ratio using the edge preserving diffusion algorithm (Brigham and Women's Hospital, Boston, MA) described in [1]. Figure 4a shows a slice through the center of the patient's head, acquired perpendicular to the patient's nose.

Segmentation: *T*he segmentation process identified the brain surface, cerebral spinal fluid, edema (fluid), tumor and the skin. A variation of the algorithm described in [3] used training points provided by the

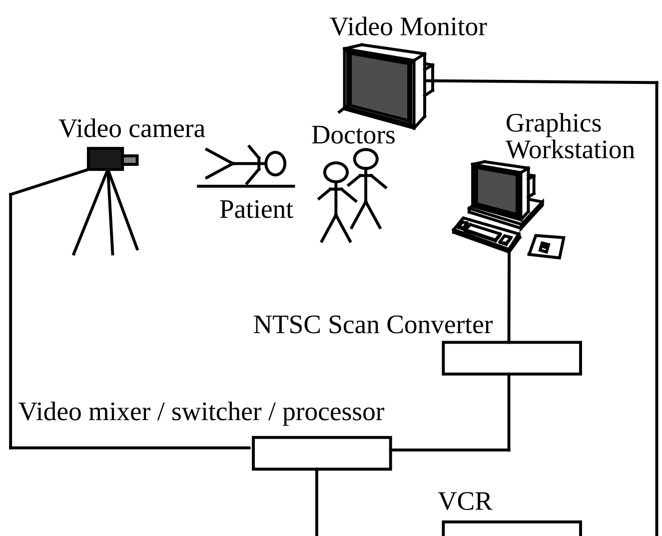

Figure 2. Video Registration.

operator to produce the segmented image shown in figure 4b (Research Workstation, GE Medical Systems, Milwaukee, WI).

Model Construction: Dividing cubes points lists were generated for each segmented tissue (Research Workstation, GE Medical Systems, Milwaukee, WI). Four separate objects were created: the tumor, the edema surrounding the tumor (green), the surface of the brain and the surface of the face, figure 4c.

The Surgical Plan: The night before the operation, the points were displayed on a Sun Workstation (Sun Microsystems, Mountain View, CA) outfitted with a custom point rendering accelerator (GE Corporate Research and Development, Schenectady, NY). The video from the workstation was converted to NTSC composite video using a CVS-980 NTSC scan converter (YEM, Okada, Japan). This computer video signal was combined with the video from a VHS camera signal using a video mixer (Panasonic WJ-AVE5). An operator manipulated the computer model of the face of the patient to align with the live video of the patient's head. The surgeon viewed the combined signal on a TV monitor and traced the outline of the tumor to be treated on the patient's shaved head. Figure 5a shows the mixed signal. The face and brain are cut away along the viewing direction to expose the tumor. The doctor also sketched the location of the patient's motor strip. By watching the combined signal on the TV monitor, the doctor moved his marking pen on the surface of the patient's head. Figure 5b shows the resulting surgical plan drawn on the patient's head.

The Operation: The operation took place the next morning at Brigham and Women's Hospital, Boston. A cart containing a workstation, video mixer, scan converter and TV/VCR was wheeled into the operating room. A video camera was positioned on a tripod behind and above the neurosurgeon. Prior to draping the patient, we aligned the live patient video and computer generated surfaces. During the operation, an operator mixed the two video signals to show the relationship between the computer models and the patient. As the surgeon worked on the tumor, the mixed video signal gave the impression that the surgeon was cutting the computer generated models. Figure 6a shows the computer generated images viewed from the video camera position. Figure 6b shows a mixed image of the computer images and patient video.

4: References

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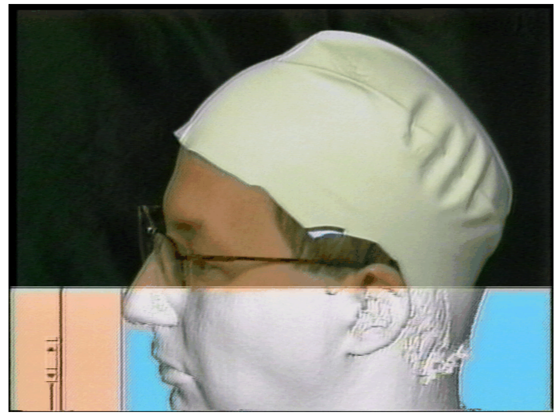
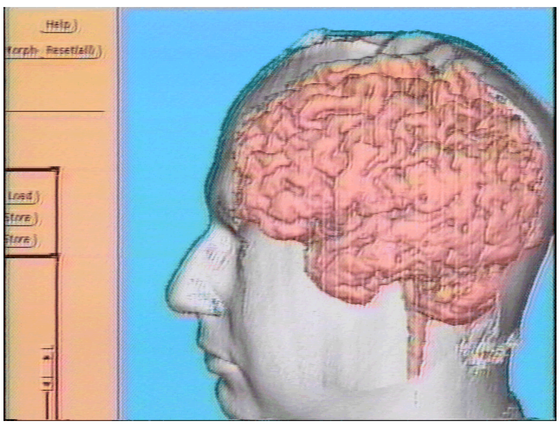
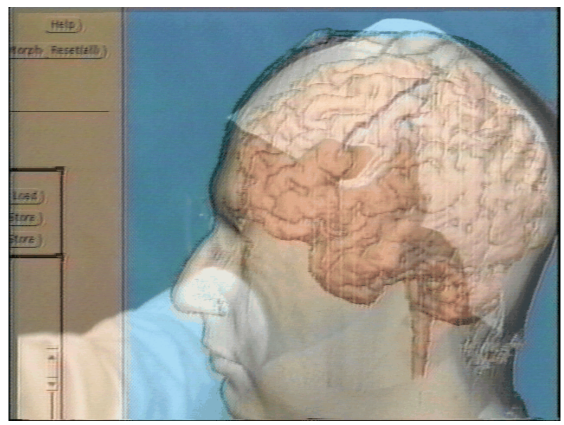


a. Alignment Left to Right

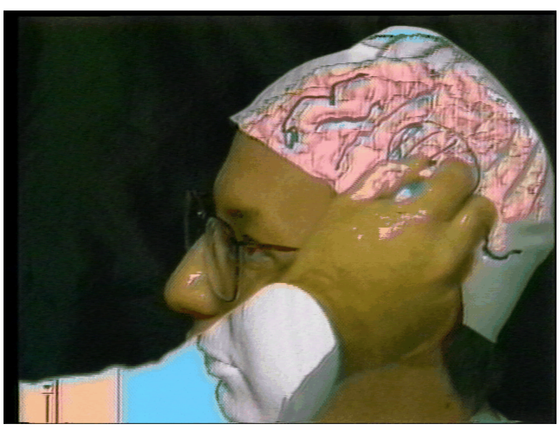
b. Alignment Top to Bottom





c. Computer Generated Models

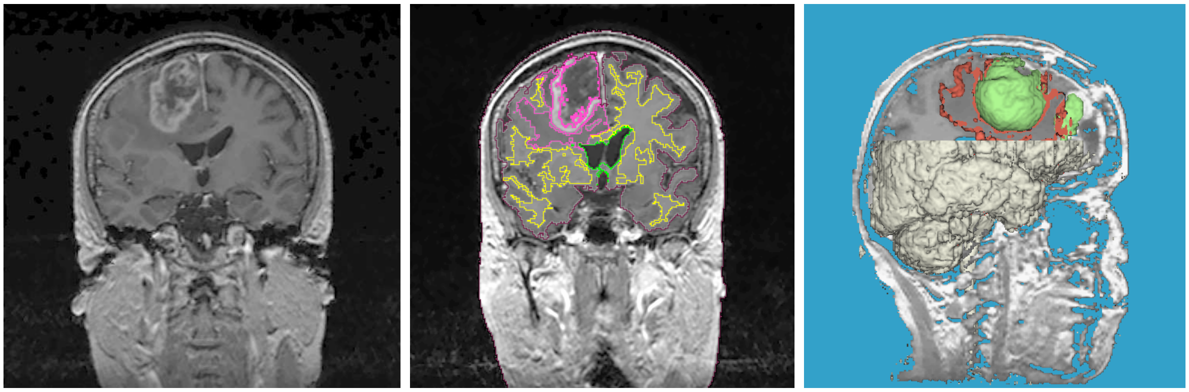
d. Computer Generated + Video



e. Luminance Keyed Video

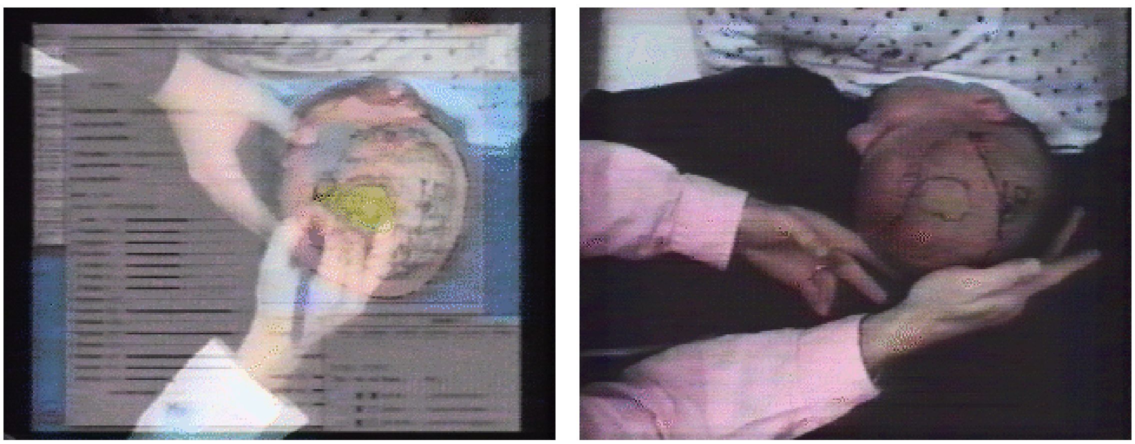
f. Live Video

Figure 3. Enhanced Reality.



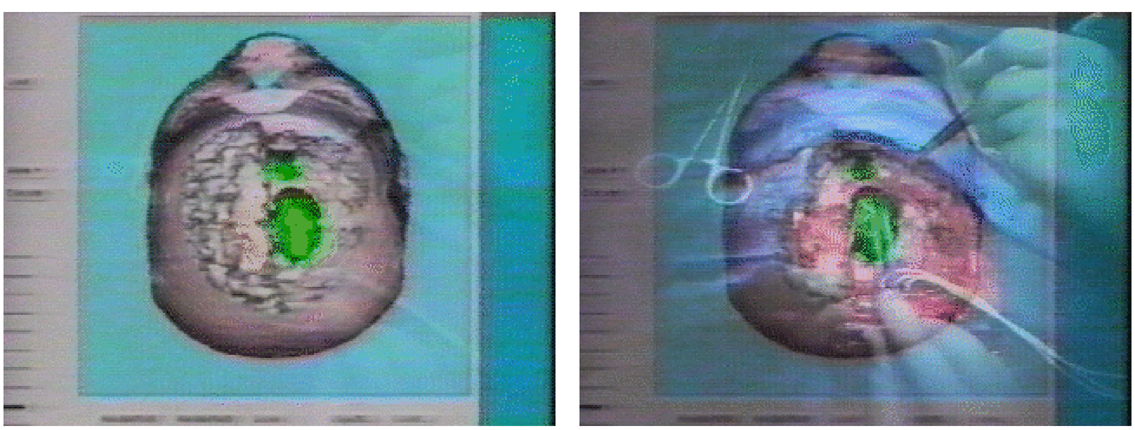
a. MRI Acquisition b. MRI Segmentation c. Model Generation

Figure 4. Surgical Planning



a. Computer Generated + Video b. Video

Figure 5. Display Prior to Operation



a. Computer Generated b. Computer Generated + Video

Figure 6. Display During Operation