The Graphic Locator

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ABSTRACT

The Graphic Locator is an application for planning MRI image acquisitions. The planned protocol, represented by a three-dimensional model, is drawn relative to previously acquired images, and can be manipulated while displayed in several images simultaneously. We describe visualization methods to accurately position acquisitions within anatomic volumes, though the techniques apply to any volumetric application.

Keywords: medical imaging, MRI, visualization, 3D, perception

1. INTRODUCTION

An image acquired by magnetic resonance imaging (MRI) represents anatomic structure within a three-dimensional slice. Positioning slices accurately and efficiently is necessary for acquiring the desired images. The Graphic Locator is an interactive program for planning MRI acquisitions. Continuous visual feedback enables the operator to position slices relative to existing images. The planned protocol is represented by a three-dimensional geometric model that is drawn relative to an existing image. Up to 16 different images can be displayed simultaneously with graphics. Each reference image can have a different location and orientation, thereby enhancing the viewer's perception of the position and orientation of the planned acquisition relative to the patient.

Locating slices properly for an acquisition is essential to ensure that diagnostic-quality images are produced in a minimal amount of time. The patient can be compromised by a lengthy stay in the MRI system or by poor images. The importance of the locating process has been noted for imaging of the knee and heart, respectively.[1,2] References have been made to aspects of the locating process.[3,4,5] However the techniques used in clinical systems are usually proprietary and seldom discussed in the literature.

The Graphic Locator combines a variety of visualization techniques to improve upon the locating process for medical applications known to us. In addition to MRI planning, our techniques are valuable for visualizing images that will be reconstructed from any volumetric data.

1.1 Display program

The Graphic Locator is a tool within the Display software component of the Toshiba FLEXART™ clinical MRI system. Display is a rich environment for imaging work, with tools for selecting, adjusting contrast, zooming, scrolling, and labeling of patient images. The Image Selector tool within Display shows an overview of a patient's entire study file, allowing images to be quickly chosen for viewing. The Display and

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Image Selector programs provide the platform for the Graphic Locator application. The programs are written in C and utilize the Motif widget set for the user interface within the X-Window System.

2. OPERATION

Each planned slice is modeled as a three-dimensional rectangular outline. Slices are organized in slice groups. Each protocol consists of one or more slice groups. The Graphic Locator displays the protocol relative to the orientation and location of the reference image (Figure 1). As the reference image is scrolled or zoomed the protocol is redrawn to match the transformed reference image.

More than one image can be displayed simultaneously. The protocol is displayed relative to each image. Typically three reference images are acquired initially: transaxial, sagittal, and coronal. Subsequent protocols are then planned relative to these three reference images (Figure 2). Any image, including those acquired at oblique orientations, can be used as a reference image.

2.1 Slice group display

There is always one active slice group that is drawn brighter than the other groups. The Phase Encode (PE) acquisition direction and slice numbers are drawn for each group. The PE direction arrow is part of the geometric model so it is transformed with the slice group. The slice numbers were originally implemented using a vector font so they could be modeled as part of the group. Since they were also transformed, the numbers could appear upside down or backwards depending on the rotation. Users found this unsatisfactory so the slice numbers were changed. The center of each transformed slice is projected onto the viewing plane (reference image) so the slice number can always be drawn with the conventional orientation using a bitmap font.

The edges of the slice group are emphasized by modeling them with cylinders instead of just a single line. A three-dimensional marker is drawn at each corner of the slice group. The design of these elements is described in section **3.2 Visual Cues**.

The slices can be displayed in three different styles. Outline style shows the edges of each slice, center line style displays the slices as I-beams, and group style draws just the edges of the entire slice group.

2.2 Translation and rotation

Each slice group can be independently positioned and oriented using the mouse. The group is translated in the plane of the reference image by clicking anywhere on the group and dragging it with the mouse. Three rotation handles are displayed for each group. A group is rotated about one of its orthogonal axes by clicking on a rotation handle and dragging the mouse around the center of the group. This is very useful for planning oblique studies. Without direct manipulation of the slices it is difficult to orient the slices to the desired anatomy. This has discouraged operators from acquiring oblique images in the past. The direct manipulation and continuous, dynamic visual feedback in the Graphic Locator make it very easy to accurately plan oblique studies.

Each slice has an adjustable thickness and an extent in two directions identified according to the corresponding MRI acquisition directions, Readout (RO) and PE. Slices within the same slice group all share the same orientation, including the same directions for RO and PE. The two directions may be exchanged by clicking the Swap Phase menu button, with a corresponding exchange of slice extent in those directions.

The Graphic Locator runs on a high-performance Silicon Graphics workstation. The reference image and the protocol graphics are redrawn at frame rate so the view of each image is simultaneously updated. Dynamic motion is achieved which enhances the viewer's perception of the three-dimensional model of the protocol. Each displayed image presents a different view of the geometric model. For example, when a slice group is moved from patient right to patient left in the transaxial view (Figure 2), the other views are simultaneously redrawn. The user can see the slice group move from patient right to patient left in the coronal view. In the sagittal view the slice group moves toward the user.

The selected slice group can be oriented exactly to transaxial, sagittal, or coronal by clicking the corresponding menu button.

2.3 Split group

The MRI system can acquire multiple slice groups at arbitrary translations and orientations. A single slice group can be split into two slice groups by clicking on the Split button in the menu and clicking on a slice. The selected slice becomes the first slice in a new group. The groups can be positioned independently. This is particularly useful for imaging the spine. A slider in the menu controls the total number of slices in the protocol. Slices are added or deleted from the currently selected group.

Depending on the type of acquisition, certain slice groups can only be bisected instead of split at any slice. In this case the Split button label is changed to Bisect and the currently selected group is bisected when the button is clicked.

2.4 Presaturation region

For some acquisitions it is desirable to suppress the MR signal in certain areas of the anatomy. This is accomplished using an MRI technique called presaturation. Presaturation regions can be automatically located at the boundaries of slice groups, or they can be arbitrarily located by the operator. These latter regions, called *freehand* presaturation regions, are displayed and manipulated in a fashion similar to slice groups. The region is displayed as a three-dimensional rectangular volume where the edges are represented by dashed cylinders to distinguish them from slice groups. The presaturation region is depicted as a finite volume for visualization even though it is unbounded in-plane. An additional control is provided to dynamically adjust the thickness by clicking and dragging on the arrow drawn along the center axis (Figure 1). A freehand presaturation region is added by clicking on the Add Freehand button. When a region is selected, it can be deleted by clicking on the Delete Freehand button in the menu.

3. VISUALIZATION TECHNIQUES

An important aspect of positioning slices is the location relative to the normal direction of the reference image. Are the planned slices in front of, behind, or do they intersect the reference image? Multiple views, as shown in Figure 2, provide additional cues to slice position, but more is needed.

3.1 Intersection lines

A technique introduced here helps the user visualize the intersection of the protocol with the reference images. Figure 3 shows an oblique slice group relative to a transaxial image. The edges of the slice group are drawn to show the overall volume that will be imaged. The intersection of each slice with the center of the reference image is calculated. The lines of intersection are drawn in bright white. The intersection is recalculated for each frame so these lines are displayed while the slices are rotated and translated. Intersection lines are calculated for each reference image that is being displayed. This has proven to be a very useful technique.

The portion of the slice on either side of the reference image can be clipped. Clipping the portion of the slice in front of the reference image along with drawing the lines of intersection effectively caps the slices (Figure 4). Capping helps to clarify which portion of the slice is in front of or behind the reference image.

3.2 Visual Cues

Three-dimensional shaded markers, edges, and controls are drawn to enhance the viewers perception of orientation. These elements are modeled as solids and rendered so the visible surfaces are shaded. This clearly indicates which edges are closest to the viewer. Initially the edges were drawn as single lines. Where edges crossed it was difficult to perceive how the slice group was oriented in 3-D even with depth-cueing. Wire-frame graphics lead to ambiguity in the perception of orientation, as in the Necker cube where either of two orientations can be perceived.[6] Replacing the wire-frame graphics with rendered three-dimensional elements clarifies orientation and front-to-back relationships within the slice group.

The center marker for a slice group is represented by a cube. The corner markers of the slice group are asymmetric in order to distinguish inside from outside. These markers resemble the corner connectors of a cubical frame. Their shading clarifies which corners are viewed from the outside. This significantly helps to determine which face of the slice group is closest to the viewer. The presaturation region thickness control and the Phase Encode direction arrow are modeled as straight cylinders with pyramid-shaped arrow heads. The rotation controls are modeled as curved cylinders with pyramid-shaped arrow heads. After each change in orientation the controls are positioned near the corner of the slice group closest to the viewer. This positioning calculation is done relative to each reference image that is displayed. Positioning the controls closest to the viewer visually reinforces the front-to-back orientation of the slice group. It also facilitates rotating the group so the direction of rotation follows the movement of the mouse.

These shaded, three-dimensional controls are visible for any orientation and are easy to distinguish from the lines of the slice group. The shading is achieved by simulating an off-center light source shining toward the center of the data space.

4. IMPLEMENTATION

The graphics hardware of the workstation supports 12 bits of double-buffered image memory but only 4 bits of single-buffered overlay memory. If the graphics representing the protocol are drawn in the overlay memory then erasing and redrawing is visible for every new frame. Fortunately, the reference image can be copied into the back buffer fast enough to support dynamic graphics. For each new frame, the reference image is copied into the back buffer and then the protocol graphics are drawn into the back buffer before the back buffer is displayed. The graphics include polygons modeled in 3-D. By drawing into the image memory the Graphic Locator takes advantage of the graphics hardware for real-time hidden surface removal and shading. Labels describing the reference image are drawn in the overlay memory. These labels do not have to be redrawn for every new frame generated by the Graphic Locator, and are only redrawn when the reference image is changed or the display window is exposed. This results in smooth motion without any artifacts.

The intersection lines and the location of the rotation controls is calculated relative to the reference image. The intersection lines must be calculated for each new frame. Positioning the rotation controls consists of calculating the nearest vertex once for the new orientation. Then the controls are translated into position using an inexpensive table look-up for each reference image. Therefore only some of the slice group graphics can simply be redrawn for each new frame using a different viewpoint for each reference image. The intersection lines and rotation controls extend the multiple view paradigm to view specific calculations for each new frame of each reference image.

5. INTEGRATION WITH MRI PARAMETERS

The Graphic Locator is a *viewer* for visualizing and planning imaging protocols. However there are limitations to what can be acquired with given parameters. For example, decreasing certain timing parameters limits the number of slices that can be acquired in a single acquisition. In order to acquire additional slices, the protocol is divided into separate acquisitions, called coverages. Limits such as the maximum number of slices per coverage are calculated by another program called LimitCalc. LimitCalc describes the protocol to the Graphic Locator. Every time the protocol is changed the Graphic Locator communicates the change to LimitCalc. LimitCalc then determines how the change impacts the protocol and returns the updated protocol to the Graphic Locator for display. Some limits are available for the Graphic Locator to enforce during interaction, such as how far a slice group can be translated. Another program called ProEdit is used to edit parameters in the protocol not accessible through the Graphic Locator. Whenever ProEdit changes a value, the change is communicated to LimitCalc which recomputes the protocol. The Graphic Locator then receives and displays the updated protocol. Whenever the protocol is being modified or recalculated the Graphic Locator receives a message, displays the clock cursor, and prohibits any additional user input.

The menu of the Graphic Locator contains controls for the TR, slice thickness, slice gap, presaturation flip angle, and total slices of the protocol being planned. The number of coverages required for the protocol, the maximum number of slices per coverage, and the total acquisition time are shown.

6. CONCLUSION

The Graphic Locator provides visualization techniques for planning MRI protocols, yet our methods apply to other volumetric data analysis applications. Shaded, modeled three-dimensional elements are superior to wire-frame graphics and eliminate perceptual ambiguities. The visual cues in the Graphic Locator are especially effective for planning oblique acquisitions. By seeing multiple views simultaneously it is easy to visualize where the acquisition will be made. Imaging the wrong anatomy can compromise diagnosis and inconvenience the patient. It also wastes time, film, and file storage. Planning quickly and accurately increases patient throughput and produces more useful images.

7. REFERENCES

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Figure 1 The Graphic Locator displays the protocol relative to the orientation and location of the reference image.

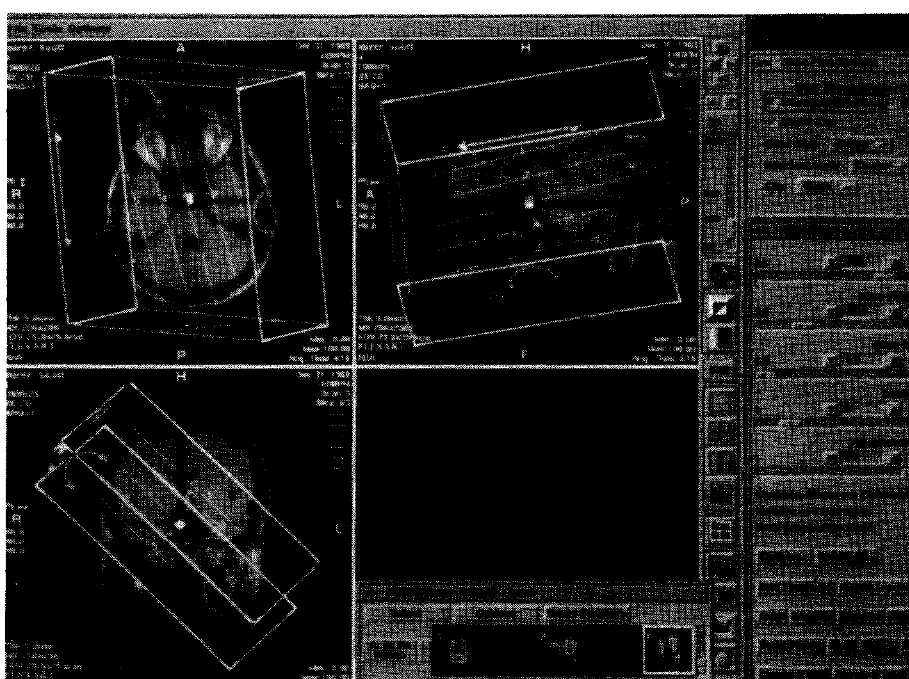

Figure 2 The protocol is planned relative to three reference images.

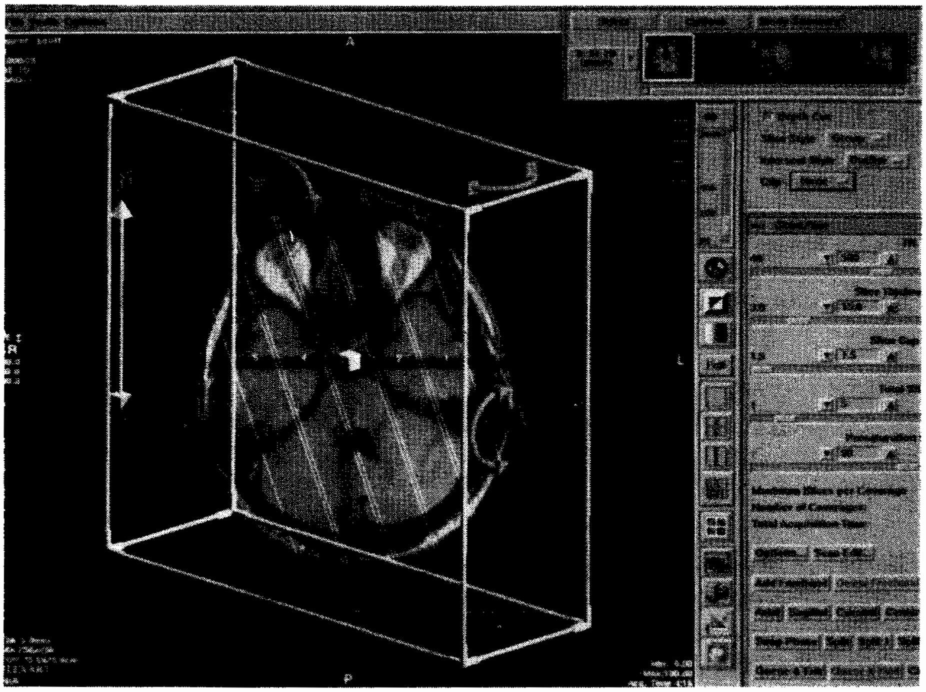

Figure 3 The edges of the slice group are rendered to show the overall volume to be imaged.The intersection of each slice with the plane of the reference image is drawn with white lines.

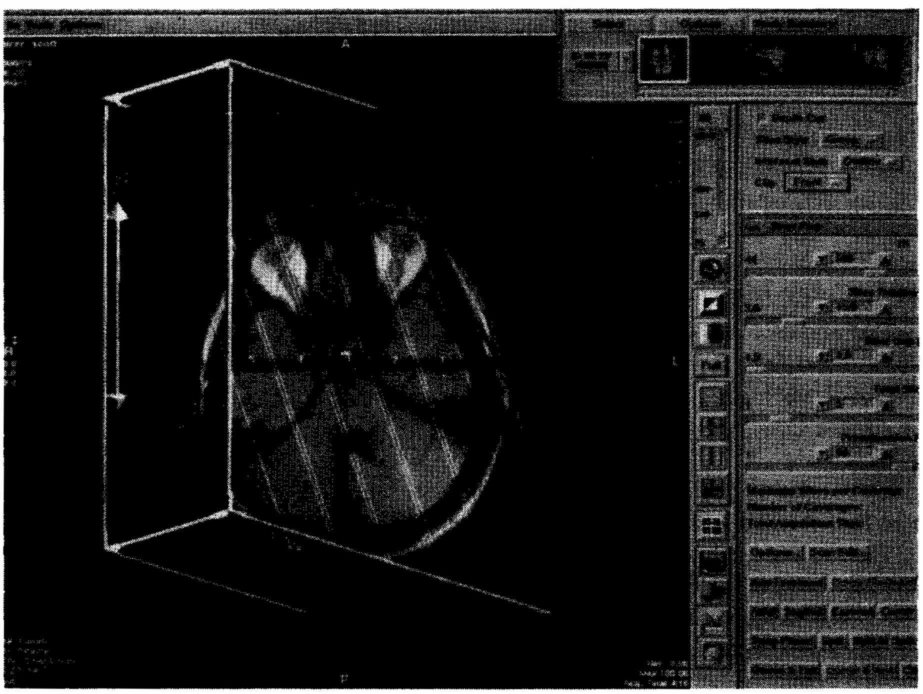

Figure 4 Clipping the slices and drawing the lines of intersection effectively cap the slices.