

# DESIGN AND IMPLEMENTATION OF A CLINICAL MSI WORKSTATION

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## Abstract

*The new diagnostic modality of magnetic source imaging (MSI) has unique processing and presentation requirements that must be addressed for it to become incorporated into clinical practice. As the combination of multislice medical imaging, particularly magnetic resonance imaging (MRI), and magnetoencephalography (MEG) functional localization, MSI is heavily computer-dependent for data preparation and evaluation as well as for data generation. The general issues of volumetric display and manipulation are compounded by the necessity for geometric accuracy and for interactive preparation of the data to be clinically evaluated. This paper discusses the design and implementation of a workstation-based system for processing MRI and MEG data and generating the combination functional/anatomical images.*

## Introduction

Magnetic Source Imaging (MSI) is the term given [1] to the combination of information from magnetoencephalography (MEG) and multislice medical imaging, primarily magnetic resonance imaging (MRI). Our initial clinical application for this technology is in pre-operative planning in order to minimize functional impairment [2], although many more applications are being developed. The most common functionality being investigated are motor sensory, visual, and language. Preliminary work at our facility with a 7-channel device has demonstrated the clinical potential of this information. With the recent installation of a state-of-the-art 37-channel biomagnetometer, we are proceeding with extensive clinical trials to evaluate the clinical utility of this functional localization technique.

In order to efficiently accommodate the quantity of data being generated, we have developed a workstation processing system. This paper will describe the system and some of the requirements for processing MSI data.

## Background

Weak magnetic fields are produced by the brain's electrical activity, and these fields can be measured by sensitive external magnetic detectors. Three dimensional localization of neuronal activity can be estimated from the spatial distribution of these magnetic fields [3-5]. MEG has an advantage over the more established electroencephalography (EEG) in that the skull is largely transparent to these magnetic fields. The solution of the inverse problem relating the multiple channels of acquired signal data to one or more idealized point sources provides

the coordinates of functional activity within the brain. The determined source locations are given an anatomic basis by their combination with high resolution magnetic resonance images. The reliability and repeatability of this approach has been demonstrated in our facility and elsewhere [6-8]. This new MEG functional information, as with an increasing number of other types of information (i.e. spectroscopic/chemical, velocity/flow, diffusion etc) must be effectively combined with images representing the underlying anatomy.

### System Design.

The first issue to be considered are the required MSI processing steps. The implementation and user interface will then be described.

#### Processing Steps

A distinction has to be made between the processing involved in generating the respective MEG and MRI data and the processing that combines the two modalities in giving MSI results. Each of these contributing modalities are heavily computer-dependent and have unique processing and interface requirements beyond the scope of the current discussion. For the time being, until MRI and MEG systems are fully integrated, some additional processing of MRI and MEG data is required to generate the MSI results. While segmentation/pattern recognition work is ongoing in our laboratory to fully automate the process, operator interaction is required for the integration of the two types of information. Specifically, the anatomical landmarks necessary for relating the two data coordinate systems must be identified in the MR image data.

At our facility, we are using a Siemens Magnetom SP63 to generate the MR image data. While the acquisition system is proprietary hardware, the system host, and eventual location of the reconstructed images, is a DEC MicroVAX II (Digital Equipment Inc., Maynard, MA) running VMS 5.4. The image slice data is available as files on the magnetic disk. ASCII text files containing calculated source locations are available from the Sun-based BTI Magnes Biomagnetometer (Biomagnetic Technologies Inc., San Diego, CA). While we have developed this workstation for our specific requirements it is likely that BTI will soon be able to provide similar processing capabilities.

The steps in combining these two sources of information essentially involve transferring and converting the data, registering the two data coordinate systems, and effectively presenting the results of mapping the point sources on the MR images.

We have established a standard MRI acquisition procedure to provide the following sets of images in approximately 30 minutes (Table 1): 1) scout/localizing slice images 2) sagittal volumetric slice images 3) multislice transverse T2-weighted 4) multislice coronal T1-weighted. The generation of this large amount of (16 bit) image data - approximately 28 MB - is typical for MRI and largely determines the performance of the workstation.

The volumetric (3D acquisition) data set is primarily used for coordinate system registration and source mapping. This set of high resolution and contiguous image slices is also suitable for 3D rendering. However, it is the heavily T1 and T2 weighted data sets that contain the

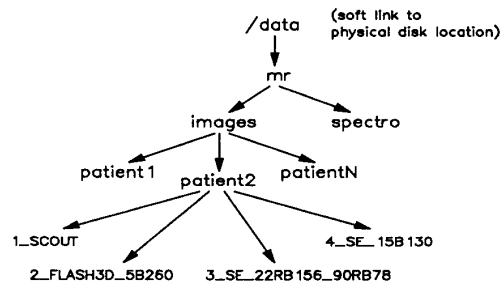
**Table 1.** Standard MR image acquisitions for MSI.

| images | orientation         | weighting   | type                   | resolution (mm) |       |      |
|--------|---------------------|-------------|------------------------|-----------------|-------|------|
|        |                     |             |                        | X               | Y     | Z    |
| 3      | mutually orthogonal | somewhat T1 | quick scout localizers | 0.976           | 1.953 | 10.0 |
| 128    | sagittal            | somewhat T1 | volumetric acquisition | 1.0             | 1.5   | 1.5  |
| 20 x 2 | transverse          | mostly T2   | double echo            | 1.0             | 1.333 | 5.0  |
| 23     | coronal             | mostly T1   | spin echo              | 1.0             | 1.0   | 6.0  |

most diagnostic MR tissue contrast and are where the source mapping will be most useful to the radiologist.

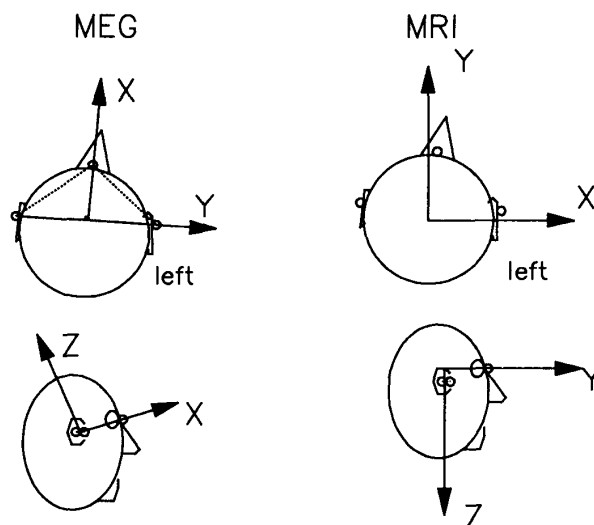
The MR images are transferred from the microVAX to the SUN Sparc1+ (Sun Microsystems Inc., Mountain View, CA) workstation using Sun's SunDNI - DECNET interface - product. This facility allows binary copying of multiple image files across the ethernet. On our network, the transfer time per image averages approximately 1.5 sec, which appears to be significantly limited by the competing demands on the microVAX. The SunDNI transfer and subsequent image header format/byte order conversion processing is controlled by a series of C-Shell scripts requiring only one initial argument. The Siemens MR keeps track of each patients group of images by a single "order" number. Since programs on the Sun cannot remotely obtain information from the MRI Numaris operating system, this number must be obtained at the MRI console.

Once the data is pulled across, it is immediately parsed into separate subdirectories containing images acquired as a group. This process uses basic acquisition parameters (e.g. time, sequence, orientation, etc) available in the MR image header. The resulting directory structure

**Figure 1.** Patient data directory structure.

is as shown in Figure 1. The directories are named according to the order performed (1\_\*, 2\_\*,...) and the scanning pulse sequence used. The image format is then converted into the Khoros VIFF format which is in standard use at our facility. Geometrical information from the MR header is also transferred to the new header. Each pixel of the MR image is of type short and so must be byte swapped for the SUN relative to the DEC ordering.

As the MEG source locations are provided in the biomagnetometer coordinates, that system must be identified relative to the 3D MR image coordinates. The MEG coordinate system



**Figure 2.** MEG and MRI coordinate systems.

established by BTI is as shown in Figure 2. This system is based on anatomic landmarks and/or markers located at the preauricular creases of both ears and at the nasion. The MEG coordinate system is defined as having an origin on the line between the right and left ear markers. The X axis is perpendicular to this line and passes through the nasion marker. The Y axis lies in the plane defined by the 3 markers and is perpendicular to the X axis. The Z axis is then normal to this XY plane. Initially, patients undergoing MR imaging have had vitamin E capsules located at each of these three locations in order to facilitate identification in the MR images. As the technologists have obtained more experience in locating the landmarks in the slice data, the external markers are now used less often.

The MR coordinate system, also shown in Figure 2, is based solely on the physical location of the image slice plane relative to the MRI magnet system. The positioning is established relative to patient anatomy during patient positioning by alignment light beams. The

anatomical (planar) location defined by the alignment lights is moved into the center (field isocenter) of the magnet which serves as the origin of the MRI coordinate system. Unless in-plane image shifts are specified, the center pixel of the image corresponds to the origin of the slice coordinate system. For a patient positioned head first and supine, the X axis is to the patients left, the Y axis is anterior, and the Z axis is down the magnet bore towards the patients feet. Therefore, for a sagittal image acquisition, the columns run from +Y to the -Y direction, and the rows from -Z to +Z. Increasing slice number runs from right to left (or -X to +X). The size of each pixel is known from the specified image field of view and the pixel sampling.

With these geometrical relationships established, the slice/pixel locations of the landmarks can be translated into MR coordinates. It is more expedient to transform the half dozen or so MEG source locations to match the MR data rather than to manipulate the large volume of MR image data. The mapping of the MEG sources and the locations in the MR data then consists of a series of coordinate transformations to align the MEG system with the MR system. Having the landmark locations, the first steps are to determine the origin and axis of the MEG system in the MRI space. Coordinate rotations about the MEG X, Y, and Z axis are performed, followed by a linear shift, in order to convert MEG locations to MRI image locations.

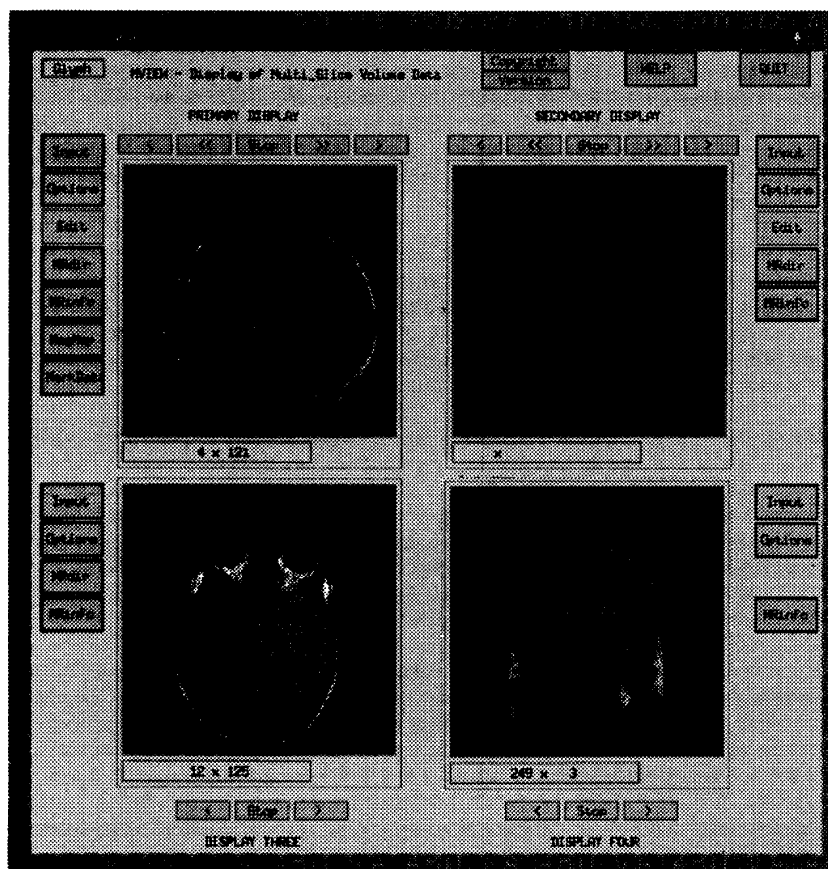
### Implementation

The requirements of the user interface are based primarily on need to identify the locations of the MEG coordinate system landmarks in the stack of 3D image slices. Once this is done the original MEG source locations can be entered and transformed into image data locations. The data can then be labelled and/or filmed as required.

This system has been developed using the interface components and software development tools included in the Khoros image/signal processing package (Khoros Group, University of New Mexico, Albuquerque, NM). This highly developed package is distributed at nominal cost and offers an extensive number of facilities that can be readily integrated into this workstation. The system is X11 R4 (now R5) based and relies only on the standard Xlib and Athena widget set. While this system has been developed on a SUN Sparc 1+, the Khoros software is portable across a wide range of platforms.

One important aspect to the design of this type of task-oriented processing system is in streamlining the interface and the operator interaction while allowing flexible processing of the data. This system is intended not to be a complete image processing workstation but is intended to assist a radiological technologist in preparing the data for subsequent review by a radiologist. Integration with other Khoros environment facilitates the occasional requirement for further sophisticated processing.

The basic system interface is as shown in Figure 3. The most obvious feature is four independent image displays, each accommodating multiple slice images data by permitting rapid paging or animation of the data. The bottom two displays also can be switched to display orthogonal reformats of the volume data appearing in either the top two displays. This layout reflects the desired endproduct of the source mapping, namely, display of all three orthogonal slices centered on the source location. The upper right display is intended to



**Figure 3.** Top level of the user interface.

display three dimensional renderings made of the volume.

In practice, the program is invoked by specifying the range (typically all) of the sagittal volumetric data to be examined in the primary display. The bottom two displays present orthogonal reformats of this data set interpolated to the in-plane spatial resolution. As the operator pages through the data, first the slice with the right ear marker, then the nasion, then the left marker are encountered - the pixel coordinates of which are entered by hand or mouse into the MEGmap subform. The spherical shape of the markers helps the operator determine the slice that best contains the anatomical landmark. This landmark identification process only needs to be done once for each set patient MEG data set. When the MEG source locations are entered, the coordinate transformation is computed and the three orthogonal slice planes corresponding to the mapped source location are displayed for operator verification.

In order to create a set of source-labeled images, the markdata subform is invoked. A variety of marker styles and sizes are available. We have been experimenting with different marker styles in order to use one that intuitively indicates the slice distance from the one containing the source. Only those images that are within the three dimensional extent of the marker design used will be updated and saved - either in place or renamed from the original. Annotation of the images is readily available by invoking the edit function. This loads the image into a Khoros tool where annotation, zooming/roaming, colormap manipulation, and several other functions are available.

While the high resolution 3D MR data set is used for display of the sagittal slice planes, it is desirable to present the T1 and T2 image data (obtained in orthogonal planes) labelled with the mapped source locations. There are immediately a couple of issues that arise with doing this. The first is in how to inform the system as to what image data is available and as to where the data resides. The second concerns the reduction in the accuracy of the source/anatomical localization when thicker slices are used.

While the basic image acquisition consists of the data listed in Table 1, quite often a variety of image data is available for an individual patient. One possible approach considered is to maintain and update a database of the data sets available for each patient. When two or more corresponding data sets are available (e.g. two coronal acquisitions, multiple echo images, etc), the operator would be offered the choice. Experience with systems that operate in this manner has indicated that it is difficult to keep such a database current and accurate given dynamics of multiple data sources (initial generation, to/from backup/archiving, versions from additional processing, removable optical media, etc).

The system implemented avoids the use of a database in favor of making it easier for the operator to designate which study to use. Once the study directory is determined, the image slice within the study that contains the MEG source location (if any) is displayed. To determine what slice data sets are available, the user can invoke the MRdir function to browse the directory tree. At each directory level, a list of files is presented and several file types are recognized. The listing description for the MR data files indicates the basic MR acquisition parameters and allows for quick selection of the appropriate study subdirectory. Once selected, the slice image most corresponding to the mapped source location is displayed.

Unfortunately, the non-volumetric acquisitions typically have thicker slices and accuracy of the source mapping decreases - being on the order of twice the slice thickness. No effective way of indicating the position of a source within the slice has been determined. Even if the depth could be indicated, the relationship of that depth location with the corresponding anatomy is lost during the acquisition of the thicker slice. Furthermore, the MEG source location is only an estimate and has a surrounding confidence volume associated with it. This uncertainty is on the order of a volumetric slice thickness but is typically better than the thicker T1/T2 weighted slices.

This workstation is intended primarily for data preparation rather than for physician review. To incorporate the MSI results into the clinical setting, the MSI information must be presented on grayscale radiographic film. The lack of the use of color to illustrate overlay information is a significant restriction. The already considerable anatomical detail present in MR images can be cluttered with the addition of symbols at source locations and it is non-trivial to

precisely label a source location without obscuring the important underlying anatomy. In addition to this is the need to label and differentiate multiple sources in the data, several of which may fall in or near a particular slice. The marker style currently favored consists of an open box-like symbol that indicates the proximity to the source-slice by the length of bars at its periphery. Now that this workstation is in place, this marker style will be refined to indicate the MEG source tolerance and to better accommodate oblique reformats through the volumetric data set.

The actual output generation of radiological films is, at present, not particularly satisfactory. The only available output device is the 3M Laser Imager (3M Imaging Systems Division, St. Paul, MN) attached to the MRI scanner. The difficulty lies in implementing direct output from the Sun to the laser camera. The camera has two input modes - neither of which is suited to the Sun. The video input of the Laser Imager does not accommodate the scan rates (1152x900, 66Hz non-interlaced) of the Sun display. Newer versions of this camera are supposedly not so limited. The alternative input is the digital interface port which, while the de facto standard among medical device manufacturers, is significantly unlike the available output sources of the Sun. A device driver to coordinate the control signal lines is also required. A sole third-party solution is known but is quite expensive. The procedure in place for filming the output involves constructing the four-quadrant image on the Sun disk, converting it to a Siemens MR format back on the microVAX, and sending it to the camera using the MR imager. While this is a somewhat clumsy process, the setting up of the appropriate MRI directories and image headers is not difficult and has the advantage of direct integration into the usual MR image-to-film data flow. It also eliminates the potential contention/collision between data coming from separate MRI/MSI consoles and uses the highly developed MR imager camera job control. The VMS procedure of keeping file versions ensures that the original (non-source-mapped) images do not get clobbered even if they have the same names. The labelled MSI images can be permanently archived along with the rest of the patient MR images.

The Sparc-based system in place has only limited 3D visualization capabilities but the system is being more fully developed in this regard. Given the large data sets and the demands of surface segmentation and shaded rendering, it is unreasonable to expect satisfying interactive visualization on this class of machine. Again, it is not the aim to provide surgical simulation but only to provide anatomical context for the source locations. To do this, we render the volumetric data set setting the anatomy transparent enough to be able to identify the source locations. As this facility is still under construction, this is currently not done for all MSI studies. Images saved from Sun's SunVision product have been used but we are currently evaluating several other packages that can be integrated into our data processing stream.

## Conclusions

We have developed a workstation environment to efficiently combine MEG and MRI data to give the new MSI result. Our implementation and some of the issues associated with MSI data processing have been discussed. As more forms of information become available, and are shown to be clinically relevant, it can be anticipated that the requirements we have encountered for effectively processing and conveying multiple sources of information will become more demanding.



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