3D Visualization of MEG Activation Records within a Semi-Transparent Talairach Model Brain

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Abstract

The use of a transparent segmented surface model brain with Talairach dimensions for the 3D display of functional (MEG) data is described. The MEG data are rst transformed to generic Talairach coordinates and then displayed within the model brain as arrows (giving the directional, positional and magnitude characteristics of MEG dipoles). Due to this transformation MEG data from di erent subjects can be displayed within the same model brain for comparison. The model brain and the functional brain data can be simultaneously manipulated in 3D in real time. The MEG dipoles can be animated according to their latency after stimulus onset. Our visualizations are providing new insights to the specialists that will facilitate (among others) the design of algorithms for the comparison of MEG data sets.

Key words: 3D Functional Brain Imaging, Magnetoencephalography, Transparent Brain Surface Model, Animation

1 Introduction

The brain produces electrical currents at every cell or set of cells which usually manifest themselves as random signals. However, when cells are activated in unison (usually in response to an external stimulus) they produce current in a particular location and direction. The resulting electromagnetic ux can be detected by neuromagnetometer arrays placed at the scalp surface. This technique, which is known as Magnetoencephalography (MEG), uses special algorithms in order to estimate the location, strength, and direction of electrical currents produced within large neuronal aggregates, in response to external stimuli. Sources of neurophysiological activity are more commonly modeled as electric dipoles, or vectors, de ned by a set of Cartesian coordinates, strength and orientation.

The most common way of visualizing MEG data so far was the projection of the position component of the dipolar sources on MRI scans [3, 10, 8]. Unfortunately this approach does not provide direction and strength information, nor does it allow free 3D manipulation of the data and the brain model, since volumetric MRI images are both expensive to compute and often result in blurring due to the excessive amount of information that is present. Badea & al. [2] produced a method which displays MEG activation data onto a patient speci c surface model of the brain. This method can not display MEG datasets of di erent subjects within a single brain model for comparison, nor can it display the 3D position of the MEG dataset within the brain model.

Direct comparison of MEG-based regional brain activity maps with the activation pro les obtained using hemodynamic brain imaging techniques, i.e. methods that measure delayed changes in regional metabolic demands rather than neuronal signaling, is only possible for pro les of a single subject but not across di erent subjects. Packages like CURRY [1] can reconstruct the 3D form of a subject's brain but can not distinguish and manipulate individual structures in the brain.

To address these issues, we have used a polygonal segmented model brain in Talairach coordinates [14] in order to provide the background for the display of the MEG data. Each MEG dipolar source is represented as a vector whose base, direction and length are proportional to the position, direction and strength of the respective dipolar source. The main impact of this technique is that the co-registration of the MEG data sets in a standard coordinate system (Talairach) makes the simultaneous display and comparison of multiple MEG activation records (even from di erent subjects) possible. Thus studies across di erent subjects can be easily performed.

Our tool was developed using the OpenDX visualization library under Linux. MEG data are converted to Talairach coordinates (using standard transforma-

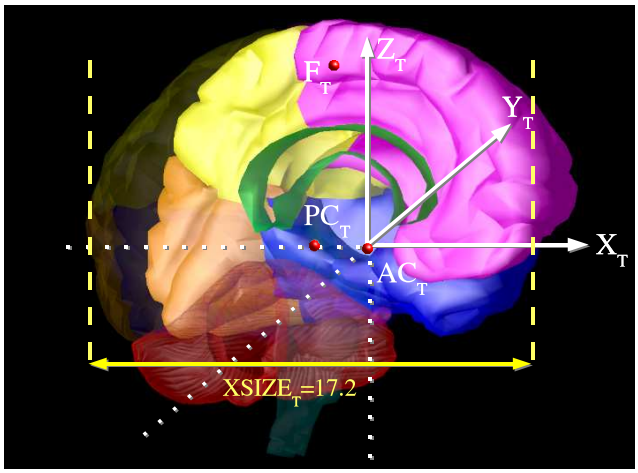

Figure 1: Polygonal Model Brain in Talairach Coordinates with AC_T, PC_T

tions from computer graphics theory) and displayed within the brain in vector form. The transparency and hue values of the brain segments and MEG data sets can be independently controlled. Multiple MEG data sets can be simultaneously animated based on activation time. The co-registration and visualization computations involve simple matrix operations and are performed in real time.

The visualization of MEG data in the above manner has resulted in signi cant bene ts. It has been possible to gain a deeper insight into the 3D behavior of activation points over time. For example it was observed that the positions of subsequent activation points (dipoles) form curves in 3D space while their direction varies smoothly within each curve. We are thus obtaining important clues which will allow us to design algorithms for the comparison of MEG activation records within and between subjects and stimuli.

2 Polygonal Brain Model in Talairach Coordinates

We have opted for the standard Talairach coordinates [14] which are well established within the medical community. To this e ect, we have taken a polygonal model brain and scaled it so that its external dimensions agree with the Talairach Atlas (see gure 1). Furthermore we have placed the AC and PC points according to their locations with respect to the Talairach brain. It is possible to display patient speci c data by rst converting to Talairach coordinates.

Our model is segmented into the regions Frontal Lobes (right and left), Occipital Lobes (right and left), Parietal Cortex (right and left), Temporal Lobes (right and left), Cerebellum, Pituitary, Corpus Callosum, Brain Stem and Hippocampus. Each region's hue and transparency value is independently controllable. In addition, we allow for new regions to be added through a simple import mechanism; the new regions must have been modelled in Talairach coordinates. Note that we have only created a quasi-Talairach model brain; it is not possible to guarantee that the geometric relationships between the internal structures of the brains used for constructing the Talairach Atlas and our polygonal model respectively are exactly the same. Another limitation of non-patient speci c brain models (such as Talairach) is that small di erences may exist between the subjects' brains and the general model.

3 Co-registration of MEG Data with Brain Model

MEG data are given in their own coordinate system which is de ned by 3 ducial points on the subject's head: the left and right ear canals (LPA and RPA) and the nasion (N). The origin of the MEG coordinate system is halfway between LPA and RPA and the positive X axis is de ned by N.

The process of combining MEG data, which o er a high resolution temporal picture of brain activity, with static structural data (the brain model) in a single coordinate system is called *co-registration*. The combined images can o er a unique tool for examining brain physiology and for developing techniques to compare MEG activation records across stimuli and subjects. To this end, we convert the MEG activation record(s) into Talairach coordinates [14, 6] and display them within the model brain.

For the co-registration, we have used easily identi able anatomical landmarks. Let AC_T, PC_T be the locations of the *Anterior Commissure* and *Posterior Commissure* points in the Talairach model brain (actually AC_T is the origin of the coordinate system, $AC_T = O_T$) and $XSIZE_T$, $YSIZE_T$, $ZSIZE_T$ be the respective dimensions of the Talairach brain in cm (see gure 1). Also let AC_M, PC_M, F_M be the locations of the AC, PC and a point on the falx cerebri in the MEG coordinate space of the speci c subject and $XSIZE_M$, $YSIZE_M$, $ZSIZE_M$ be the respective dimensions of the subject's brain in cm. AC_M, PC_M, F_M can be identi ed by the user in MRI space and then converted to MEG space using standard software, such as MRO from 4DNeuroimaging. The Falx point is used to identify the 'up' direction as we shall see below.

The standard affine transformations translation (T), rotation (R_X, R_Y, R_Z) and scaling (S) [15, 7] will be used to implement the co-registration. The co-registration algorithm follows:

- Translate $MEGpoints$, PC_M and F_M by AC_M
  $MEGpoints' = T(\ AC_M)\ MEGpoints$
  $PC' = T(\ AC_M)\ PC_M$
  $F' = T(\ AC_M)\ F_M$
- Let $PC'' = \ PC'$
- Apply A= (Align $\overrightarrow{PC''}$ with $\overrightarrow{X_T}$) $= R_Z(\theta_2)$ $R_Y(\theta_1)$ to $MEGpoints'$, F' (see gure 2)
  $MEGpoints'' = A\ \ MEGpoints'$
  $F'' = A\ \ F'$

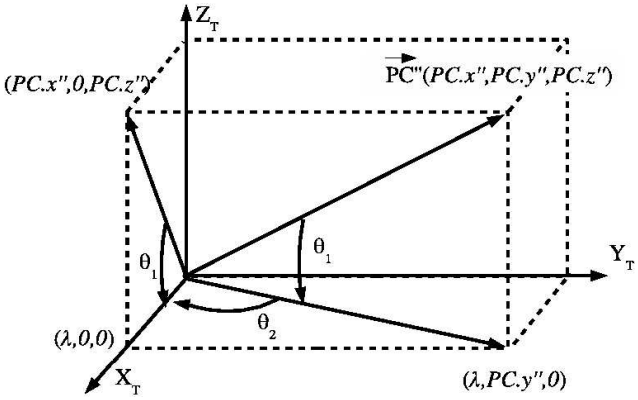

Figure 2: Alignment of $\overrightarrow{PC''}$ with $\overrightarrow{X_T}$

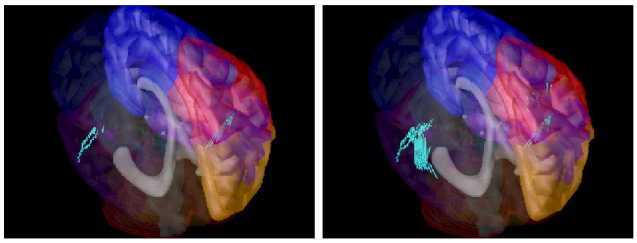

Figure 3: Two frames of a progressive MEG dipole sequence animation for Wernicke-Language stimulation at 318 and 864 msec respectively on a single subject (4008)

- Rotate $MEGpoints''$ around X_T to match other axes (up direction)
  $MEGpoints''' = R_X(\theta_3) \quad MEGpoints''$
- Scale to Talairach dimensions
  $MEGpoints_T = S\left(\frac{XSIZE_T}{XSIZE_M}, \frac{YSIZE_T}{YSIZE_M}, \frac{ZSIZE_T}{ZSIZE_M}\right)$
  $MEGpoints'''$

Simple calculations give the following values for $\theta_1, \theta_2, \theta_3$ and the matrix A:

$\theta_1 = \arcsin\left(\frac{PC.z''}{\lambda}\right)$

$\theta_2 = \arcsin\left(\frac{PC.y''}{V}\right)$

$\theta_3 = \arctan\left(\frac{F.y''}{F.z''}\right)$

$$A = \begin{bmatrix} \frac{PC.x''}{V} & \frac{PC.y''}{V} & \frac{PC.z''}{V} \\ \frac{PC.x''\cdot PC.y''}{\lambda\cdot V} & \frac{\lambda}{V} & \frac{PC.y''\cdot PC.z''}{\lambda\cdot V} \\ \frac{PC.z''}{\lambda} & 0 & \frac{PC.x''}{\lambda} \end{bmatrix}$$

where

$$\lambda = \sqrt{(PC.x'')^2 + (PC.z'')^2}$$

$$V = \sqrt{(PC.x'')^2 + (PC.y'')^2 + (PC.z'')^2}$$

3.1 Multiple Data Sets and Animation

The use of a single generic structural model for the brain is useful for simultaneously displaying multiple MEG activation records, for comparison. Essentially, they are separately co-registered with the Talairach brain by providing di erent co-registration data (AC, PC, Falx and size) for each activation record (see g- ure 4). Each MEG record is displayed in a di erent color. The dipolar sources comprising each MEG activation map can be animated so that they appear in the sequence dictated by their order of activation (gure 3). These can be displayed as a single travelling arrow which can optionally leave a trace. Experimentation in visualizing many MEG activation records resulted in a number of interesting observations regarding their behavior. For example it appears that the positions of subsequent activation points form curves in 3D space while their direction varies smoothly within each curve. These clues can help us in designing clever algorithms for the comparison of MEG activation records within and between subjects and stimuli.

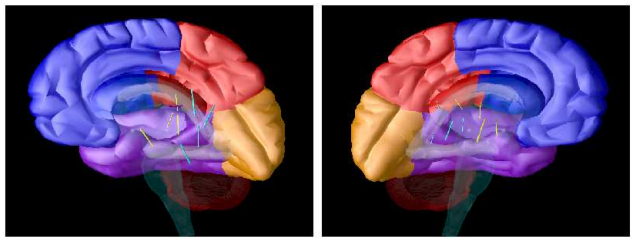

Figure 4: Left and Right hemispheres for Wernicke-Language (Yellow) and Primary Auditory (Cyan) stimulations (averages per subject) across four subjects

4 Case Study

In order to demonstrate the use of the model we have selected data obtained from four healthy volunteers during performance of a word recognition task. The task was developed as part of the rst MEG activation and analysis protocol used for pre-surgical mapping of receptive language function and has been successfully validated against invasive brain mapping techniques (Intracarotid Sodium Amytal test and electrocortical stimulation mapping) [5, 4, 12]. Data were recorded using a whole head neuromagnetometer equipped with 248 axial gradiometer sensors (WH3600, 4D Neuroimaging, San Diego, CA). Event-related magnetic responses elicited by as few as 30 individual word stimuli are rst averaged together to improve signal-to-noise ratio in the data. Subsequently the distribution of magnetic ux on the scalp surface is visually inspected at each successive 4-ms time slice to identify dipolar distributions over the left or right side of the head (or both). Dipolar distributions, each consisting of a region of magnetic out ux and an adjacent region of magnetic in ux, are typically observed for several hundred milliseconds after the onset of the spoken word stimuli.

A standard, least-squares algorithm is then applied to the magnetic ux values from a subset of gradiometers covering each set of magnetic ux extrema, independently [11]. In a series of iterations, the algorithm is evaluating the goodness of each t (hypothetical source solution) against the observed data. Dipolar sources that successfully account for $> 95\%$ of the

variance in the observed magnetic ux recordings were considered acceptable. Invariably, several such successive activity sources are computed in each hemisphere. The majority of sources are localized in superior and middle temporal regions. Early sources (computed between 50 and 200 ms) are localized in the superior temporal gyrus in the vicinity of the primary auditory cortex. The number of these sources and their cumulative strength is typically symmetric across hemispheres. Later sources display clearly asymmetrical patterns, with a greater number (indicating longer-lasting activation) and strength in the left hemisphere in the majority of right-handed participants. "Late" activity sources are typically localized in association auditory cortices and in the adjacent Wernicke's area, which is an indispensable component of the brain mechanism involved in the analysis of speech sounds and in word recognition. Sources are also found in the posterior portion of the middle temporal gyrus, an area also involved in word recognition and probably also in comprehension. This pattern of activity has been observed in over 200 healthy volunteers tested in this protocol by our group and others [9, 13].

Here we present data from four participants. For each case activity source parameters corresponding to the "best" tting dipolar source, one for the "early" and one for the "late" magnetic response component, were normalized based on the dimensions of each participant's brain (obtained individually from high resolution MRI's). Figure 4 displays the resulting vectors in the Talairach brain (left and right views) while in gure 3 we display two frames of a progressive MEG dipole sequence animation for Wernicke-Language stimulation.

5 Acknowledgements

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