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An Interface for Analyzing and Integrating Different Sensory Modalities

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Abstract: This MATLAB interface is aimed at analyzing and integrating two different imaging modalities optical topography system (OTS) and magnetic resonance imaging (MRI). MRI provides information about the anatomical structure of the brain, while OTS displays the changes in the cerebral blood flow in the form of a topographic image. Eight subjects underwent an MRI and OTS exams at Miami Children's Hospital, during which an anatomical MRI images and optical topographic maps were acquired. In order to map the motor functional areas in the brain, a functional experiment is performed by using OTS and is based on a repeated finger tapping task alternated with relaxed states. The developed interface displays a sequence of 2D topographic maps depicting the finger tapping experiment in a form of a movie. Moreover, it displays the anatomical MRI slices in different views (2D-3D): transaxial, sagittal, coronal; and 3D head model constructed from the anatomical MRI slices. Therefore the 2-D videos now extend to 3-D videos of the topographic maps that can be projected on 3-D head models or on the cortical surface of the brain. The interface integrates both modalities MRI-OTS in 3D revealing excellent prospects in localizing the functional activation change that is seen by OTS on the brain model. The proposed interface integrates an important visualization platform for neuroscience studies, assisting as a consequence neurosurgeons to localize key functional regions in the brain.

Key-words: Optical Topography (OT), Magnetic resonance imaging (MRI), OT-MRI Integration

1 Introduction

The complex research field of diagnostic brain imaging can be classified into two major developments: (1) structural imaging (assess structure of the brain in order to analyze its anatomy), and (2) functional imaging (assess brain function using biochemical, electrical, or physiological properties of the brain in order to map, measure and localize brain activity).

A functional imaging technique was developed by Hitachi (ETG-100), known as Optical Topography System (OTS), which is based on visible and near-infrared light. This machine measures the changes in the two forms of hemoglobin in the blood (oxy and deoxy hemoglobin). When activation occurs in a particular area in the brain, the blood supply to that area as well as the level of oxy-hemoglobin would increase. The changes in oxy and deoxy hemoglobin can be viewed by means of a topographical image [1]. The imaging of reflected light that measures neural activity has experienced a widespread use in the investigation of functional architecture of the cortex [2], [3], [4]. The proposed research has been conducted by using the OTS and MRI machine in synergy. The main objective of the study was to superimpose the changes revealed in the topographic maps generated by OTS on the 3D head/brain model in a movie form. This integrated process is thus designed to enable researchers and clinicians to localize on the structural MRI the activation seen through the topographic image.

2 Optical Topography System

2.1 Measurement Principle

The OTS measures the activation of a particular area in the brain by sending a weak near infrared light of about 1.5mW from optical fibers placed at the scalp. The light, which can pass to a depth of 3 cm, penetrates the skull reaching the cerebral cortex, and then scattered by hemoglobin in the blood. Light is partially reflected back to the scalp and is detected at a distance of 3cm across the scalp, the detected light passes through the regions inside the skull. The system measures as how active the specific regions of the brain are by continuously monitoring the blood hemoglobin levels, while

having the examinee do some specific action or task (e.g., finger tapping task) [1].

2.2 Data Acquisition

Eight healthy subjects aged 20-25 years were selected to do an anatomical MRI exam and a finger tapping test using the ETG100 Optical Topography System of Hitachi Medical Corp, under expert clinical supervision. The finger tapping test is a general demonstration of the cerebrum functional activation measurement, which is not affected by a surrounding environment, and is one of the most consistent tests administered.

During the stimulus, subject taps his/her finger (tapping order: forefinger-little finger). Stimulus and resting periods are repeated five times, alternately in all the subject studies. The probe holder is attached to the motor area, and aligned so that probe number (Blue5) is located at C3 scalp electrode and probe number (Blue1) is located at C4 scalp electrode, in accordance with the standard "10-20 system of electrode placement" as illustrated in Figure 1. The above settings were used for all the subjects.

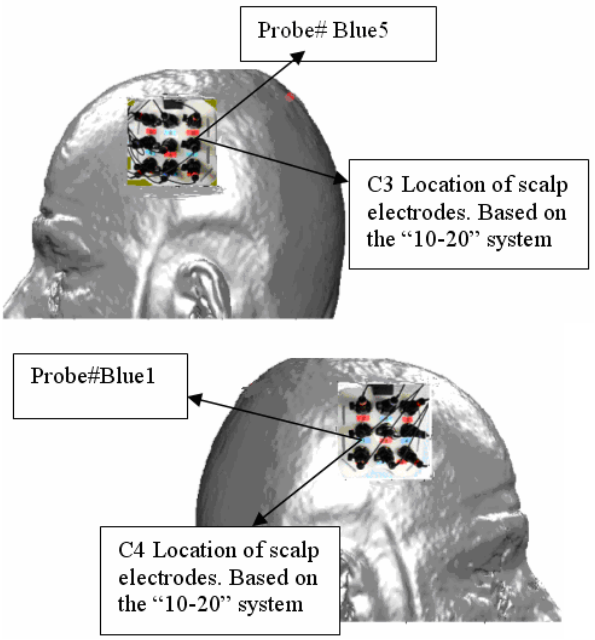


Figure 1: Holder attached to the motor area

3 Interface Development Process:

The main application window of the interface is exemplified in Figure 2. The developed interface allows the user to select and analyze a study of interest, visualize the change in oxy and deoxy hemoglobin in form of 2D movie. In this section the construction of the Topographic maps is discussed.

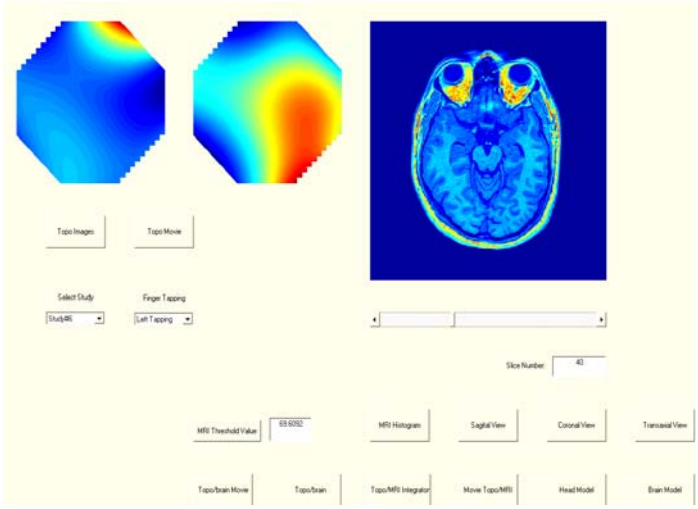


Figure 2: MATLAB Interface developed for analyzingd and integrating different sensory modalities.

3.1 Construction of the Topographic Image

In order to map the changes in brain activation (hemoglobin concentration), it is necessary to know the accurate location of the data. The white points shown in Figure 3 illustrate the positions of illuminated points (transmitters), and the black points show detected points (detectors). The point midway between an illuminated point and a detected point is defined as a measured point (channel). The channels detect both the oxy- and deoxy-hemoglobin changes and are denoted here by numbered squares.

The topographic images from left and right hemispheres are thus created from the samples of data generated by the OTS. The sampled points or measured points (channels 1-24) are placed in two (4x4) arrays for further analysis. In order to construct a square array (4x4), the missing points will be interpolated using averaging interpolation, which consists of averaging between the closest measured points.

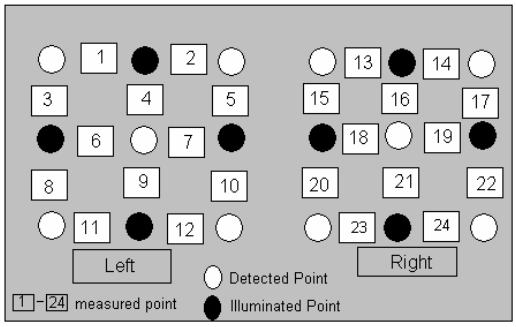


Figure3: Probes placement architecture

Several interpolation methods have been tested, but the best interpolation results were achieved using Spline interpolation. The (4x4) matrix is interpolated to a 31x31 array, and the resulting matrix is displayed as a topographic image as in Figure 4. The red color (darker gray) indicates the region of activation.

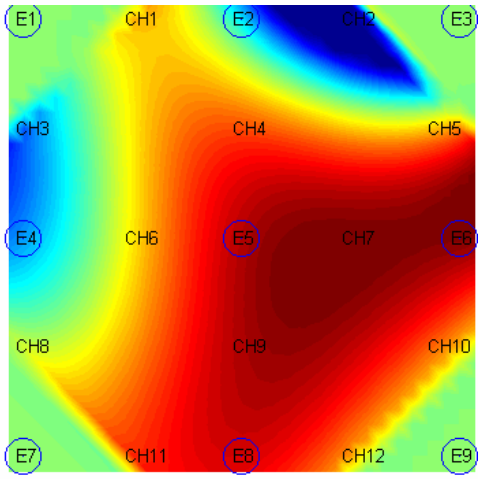
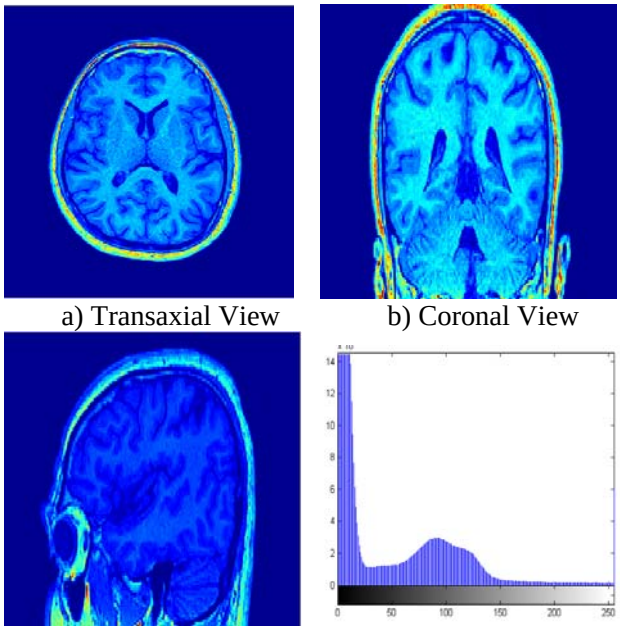


Figure 4: Topographic image displaying the oxyhemoglobin

4 Different Anatomical Views and 3D Reconstruction for the MRI Slices:

The interface allows the user to display the MRI slices in three different anatomical views (transaxial, coronal, and sagittal) as in Figure 5. Moreover, it implements the basic global thresholding algorithm as preliminarily step for 3D reconstruction and for each study it allows the user to view the histogram for the volume of MRI slices as shown in Figure along with the value of the threshold that is being used for segmentation.



a) Transaxial View b) Coronal View

c) Sagital View d) Histogram for a volume of MRI slices.

Figure 5: Different anatomical views for MRI slices

The developed interface allows the user to construct Head/brain models as shown in Figure 6. A volume rendering is created based on “Marching cubes: 3D surface construction algorithm” [5] after using the computed threshold on the MRI slices.

a) Head Model b) Brain Model

Figure 6: Illustrative head/Brain models constructed from a volume of anatomical slices

5 Integrating Optical Topographic Maps and MRI

The developed window application provides integration between optical topographic maps and MRI, which will allow the neurosurgeons to localize and visualize the changes in brain activation by displaying a movie of topographic maps on the head/brain model.

The first step in the integration process is to localize the probes of the OTS on the head model (constructed from the MRI slices).

5.1 Detection of the Probes Location

An algorithm is developed that will first identify the regions on the 3D head model from which the topographic image generated by OTS was taken. The algorithm works as follows: the user is asked to identify the location of the left and right auricular, nasion and inion points by clicking on the head model. Then by using the geometry of the "10-20 system" of electrode placement an automated algorithm will identify the location of the scalp electrodes C3, C4, and Cz on the head model, where C3 is equivalent to probe#Blue5, and C4 is equivalent to probe#Blue1..

5.2 Determining on which Transaxial Slice (C3-C4) are Located:

Using Figure 7 as a reference illustration, the following measures are used to determine on which transaxial slice the scalp electrodes C3 and C4 are located.

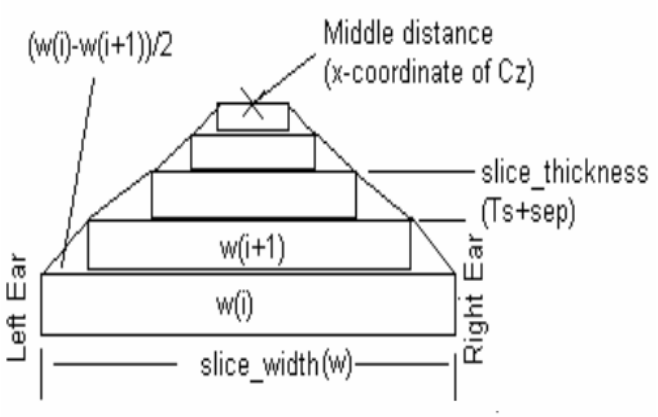


Figure 7: Geometry of MRI slices

- The width of each transaxial slice is determined and stored in vector *w*.

- To compute the circumference $C_{LR}(N_s)$ from the left ear to the right ear, the following function was developed to compute a partial sum over a number of continuous slices:

$$C_{LR}(i) = \sum_{k=1}^{i} 2 * \sqrt{(T_s + \Delta_s)^2 + \left(\frac{w(k) - w(k+1)}{2}\right)^2} \qquad (1)$$

where i indicates which transaxial slice is used, $w(i)$ is the width of slice number i, N_s is the total number of transaxial slices, Δ_s is the separation distance between the transaxial slices and T_s is the slice thickness. For the final slice, just the width of the slice is added to the circumference $C_{LR}(N_s)$. When $i = N_s$, this function returns the circumference from the left to the right ear.

- To determine the 30% distance, the following function is defined:

$$F(i) = \sum_{k=1}^{i} (C_{LR}(k)/2) \qquad (2)$$

In equation (2), i and k represent slice numbers, $i = 1, 2, \ldots, N_s$ and $k = 1, 2, \ldots, i$. Then, equation (2) is transformed to provide the relative function F_{rel}:

$$F_{rel}(i) = \frac{F(i)}{2 * F(N_s)} \qquad (3)$$

- Check when $F_{rel}(i) = 0.3$, which is 30% of the total circumference C_{LR}. The value of i when this condition is satisfied will correspond to the transaxial slice where the scalp electrodes C3 and C4 are located.

5.3 Locating x-coordinate of scalp electrode Cz:

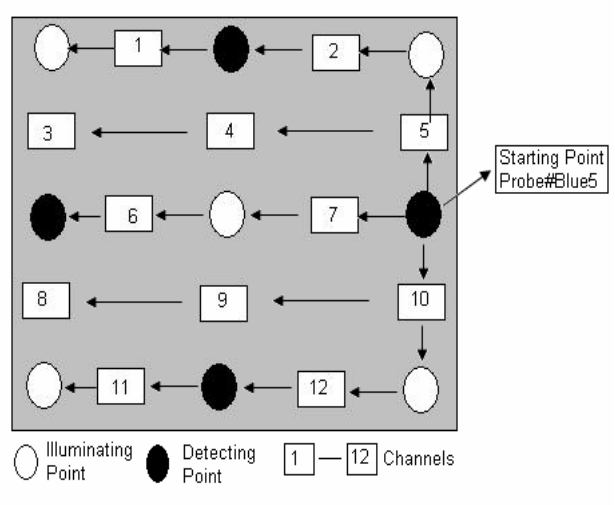
The transaxial slice where F_{rel} is equal to 50% is determined (corresponds to the z-coordinate of Cz), and the center of the slice is located and used as the x-coordinate for the scalp electrode Cz.

5.4 Locating y-coordinate of scalp electrode Cz:

The length from the nasion to inion is computed then 50% of the total length (Nasion-Inion) is located. The pixel where the length is 50% will be the y-coordinate.

Then, the remaining probes will be determined by pixel walking on the head model a distance of 2.6 cm (in accordance to 2D projections of the electrode spacing) in perpendicular direction (up and down) with respect to C3 and C4 as illustrated in Figure 8. Electrodes C3 and C4 are used here as startup positions. After determining the location of the probes all the pixels that fall within the boundaries of the probes are determined, extracted and stored in an

array. Then the topographic images are warped to the extracted pixels as shown in Figure 9.



Left probe architecture

Figure 8: Using probe architecture to extract pixels from MRI volume that falls within the probes

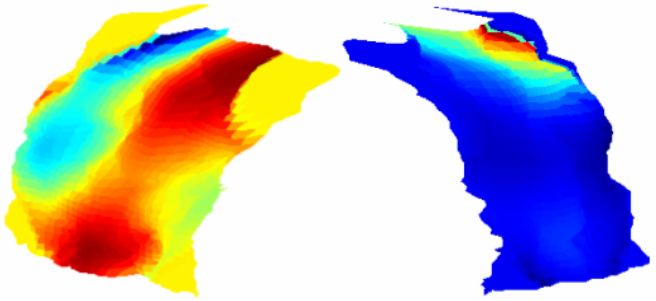


Figure 9: Warped topographic images

6 Results

The developed interface yields an accurate result.

In order to verify the results obtained, a comparison is made between the fiducial markers (Vitamin E) placed on the patients head during the MRI test to localize the probes location and an automated computer program that will detect the probes position. The integration of topographic maps to anatomical MRI is illustrated in Figures (10, 11).

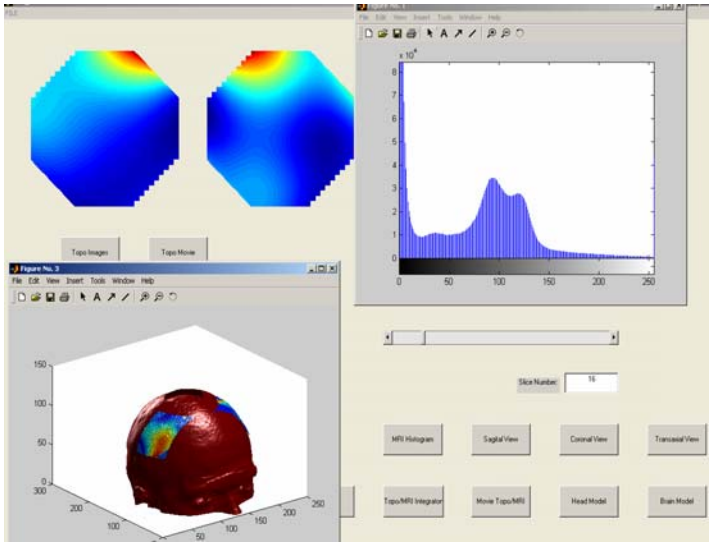


Figure 10: An interface application displaying the results obtained by integrating OTS with the head model.

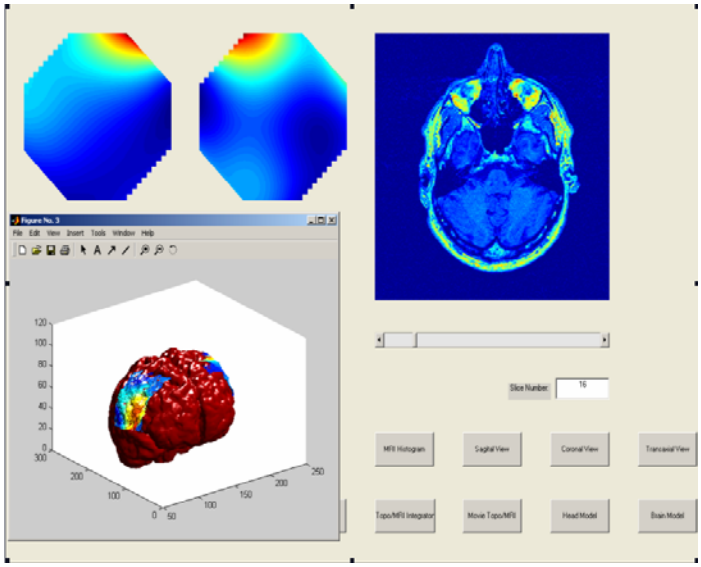


Figure 11: An interface application displaying the results obtained by integrating OTS with the brain model.

The developed window application is capable of mapping the functional areas of the brain by displaying a video of topographic maps on the head model.

6 Conclusion

This developed interface introduced a new integrated approach between two different modalities, namely MRI and OTS. The objective was to localize and visualize the changes in brain activation by displaying a movie of topographic maps on the head/brain model.

The algorithm involved the integration of key imaging techniques coupled with 3D rendering and a new integration process that allowed for the OTS image to be superimposed correctly on volumetric MRI slices.

The validation process proved very useful by making use of fiducial markers (Vitamin E) placed on the patients head during the MRI data acquisition. Through such markers it was possible to effectively register the results obtained through the automated algorithm with the actual probes positions.

Foreseeable applications of this method will come in support of other diagnostic studies performed in our earlier work [6], [7], [8], [9], and will serve researchers and clinicians as an integrated multi-modal sensory-based research and diagnostic platform.

Acknowledgments

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