Multimodal application for visualization and manipulation of Electrocorticography data

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Summary

Despite the existence of several treatments for epilepsy control, nearly one third of the patients still need to undergo surgery in order to control the seizures. Especially in these cases, it is essential to locate precisely the area responsible for the seizures. With the advances in technology the number of techniques to help in this diagnostic has increased dramatically as well as the resolution of the resulting images. A surgeon can now have information about brain activity from several exams: EEG, MRI, CT, PET and Electrocorticography (ECoG) where epidural or subdural electrodes are used to record the Electroencephalogram (EEG). Many software applications are used to analyze these data, but most of them do not provide any facility to super-impose in the same view information from different techniques. In ECoG, for example, it is essential for the surgeon to locate the electrodes within the brain of the patient in order to plan the surgery and avoid removing critical areas. In this paper, we present the first version of a software whose objective is to combine in the same application the data coming from ECoG, MRI and CT to provide the surgeons with a tool that combine easily all the data in the same visualization tool to facilitate the interpretation of the available information as a whole.

Keywords

Electrocorticography, MRI and CT data, 3D Visualization, Volume Rendering

1. INTRODUCTION

Epilepsy is a chronic condition characterized by spontaneously recurring seizures [Gastaut1973]. It affects approximately 0.5-1% of the population in industrialized countries [Hauser1998] and the variety of causes is extensive and not always easily detectable. These seizures are temporary abnormal electro-physiologic phenomena of the brain, in the majority of these cases, patients suffer from localization-related ("focal") epilepsy [Crawford2000].

The clinical objective of epilepsy treatment is, first, identify the area responsible for the seizures - the epiloptogenic area - and, second, control the seizures occurrence based on that area localization. This control can be made through AEDs (Anti-Epileptic Drugs), but despite the advancements of these treatments, nearly one third of patients are resistant to them. In these cases, surgery is a valid option which has improved chances to render a patient seizure free in relation to AED treatment [Wiebe2001].

To pinpoint the epileptogenic area in epilepsy surgery candidates undergo an extensive pre-surgery evaluation, which may include several tests from imaging modalities (structural and functional) to brain electric activity monitoring. These modalities may be non invasive such as Electroencephalography (EEG), Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Positron Emission Tomography (PET) or intrusive like invasive monitoring of brain electrical activity - Electrocorticography (ECoG) [Enger1994; Jayakar1999]. ECoG records the brain electrical activity through epidural or subdural electrode arrays placed directly on the cerebral cortex as shown in Figure 1.

The main aim of the present work is to describe the early stages of the development of a tool to help neurosurgeons and radiologists in the pre-surgical evaluation in the context of collaboration with the ongoing Epilepsy Surgery program in the University Hospital of Coimbra (HUC). The presented tool aims at supporting the visual combination of brain morphological data (MRI) with the ECoG information along time. The tool presents an unified user interactive interface which enables both visualization and analysis of multimodal medical data. It integrates visually several modalities and data image processing results obtained with existing tools commonly used in brain imaging field.

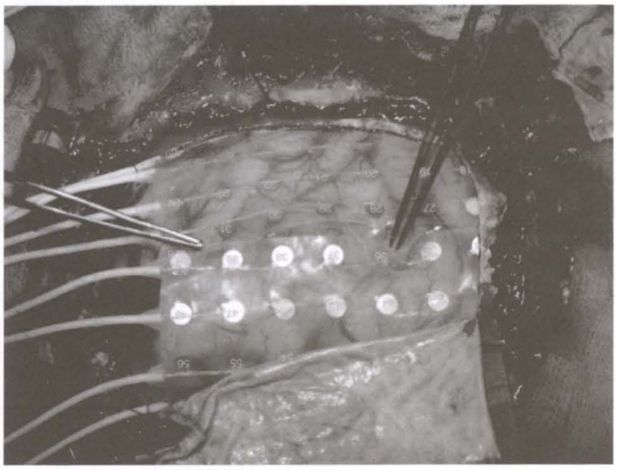

Figure 1: Electrocorticography grid placement.

2. STATE OF THE ART

2.1 Medical Applications

In neuroimaging field there are two main issues in visualization: the support of multiple modalities and the visualization of the data. Most of the available tools cope with several modalities through the support of imaging formats support that generic volumetric data sets (suitable to store MRI, CT, PET acquisitions). The most popular formats range from the standard DICOM [DICOM] to de-facto standard in the neuroimaging community, the Analyze format [Analyze] and more recently its open source evolution the NIFTI format [NIFTI].

For the neuroimaging visualization tools, MRIcro [MRIcro] might be considered as paradigm. Although it provides a simple graphical interface, it supports most of the standard imaging features popular in the imaging field such as 3 view standard visualization (axial, sagital and coronal view), window level, palette selection, ROI selection and 3D volume rendering. In addition, it supports overlay of different co-registered information which, in clinical context, is crucial in visually relating, for instance, brain morphology obtained with MRI with functional information like PET [Kiebel1997].

Another interesting application is VolView [Volview]. Created by Kitware, this software is based on volume rendering and allows a quick exploration of complex medical or scientific images. Beside the visualization capabilities, the application also comes with a set of additional functions for filtering, contouring, measuring or creating histograms from the images under analysis.

Many other similar applications exist, for example: 3D Slicer[Slicer], etDips [etDips], Julius [Julius] or AMIDE [AMIDE].

The drawback is that none of these solutions was developed specifically to visualize information from ECoG or supports it. ECoG information is not an image as it consist of local measurements of the electrical in each electrode along time. Visualizing ECoG data implies co-registering ECoG electrodes onto brain surface morphology (from MRI) in order to relate spatially the electric activity with the brain morphology. This is crucial in the identification of brain areas related with epileptiform activity or with noble functions such as speech, memory among others. This is possible by mapping which electrodes located over brain cortex are related with specific activity patterns associated with specific brain functions.

The extraction of the ECoG electrode positions poses a challenge. The correct spatial location of the electrodes can only be obtained using CT volume that, in turn, must be co-registered with the brain morphology (MRI) in order maintain a correct spatial map the ECoG measurements and the brain surface and related electrodes.

The objective of the present tool is to provide a single interface that allows interactive multimodal visualization of brain surface electrical activity (ECoG), as well as a electrode position extraction (CT) facility and brain morphology data (MRI).

2.2 Desired Functionality

At an early stage of the tools specification we isolated some of the more relevant functionalities necessary to our application:

- Automatic extraction of electrode location. The exact position of the electrodes can be easily detected in a CT scan. An interesting functionality would be the extraction of the exact electrode position from a pre-registered CT scan, without any need of manual selection from a user.
- 3D Visualization of MRI and CT as 3D volume and 2D slices, since these are the more common representations.
- Possibility to visualize a 2D schematic of the electrode-grid and map the associate the electrodes in the 2D grid with the 3D electrodes located in the brain.
- Possibility for the user to add meta-information to each electrode of the grid. This meta-information can be for example a classification of the electrodes providing functional information: identify the electrode in an area related to language, memory, motor, seizure start or seizure propagation area.
- Finally and more important, the visualization in the 3D and 2D view of the MRI information registered with the electrodes positions. This visualization is especially valuable for the surgeon who can easily associate the electrical activity measured by the electrodes with the morphological data in the MRI.

At this stage, the co-registration of CT and MRI is supported by an exterior application, SPM [SPM]. SPM is a complex framework that provides implementations of several analysis and processing protocols useful in the neuroimaging field namely the spatial co-registration of different volumetric datasets which we employ when co-registering CT with electrode positions and the MRI with the brain morphology information.

3. IMPLEMENTATION

3.1 Development Tools

The software was developed in C++ and uses the Visualization Toolkit (VTK) [Schroeder1998] for visualization purposes. VTK is an open source graphics application that supports a wide variety of visualization algorithms including scalar, vector, tensor, texture, and volumetric methods. It also provides more advanced modeling techniques such as implicit modeling, polygon reduction, mesh smoothing, cutting, contouring, and Delaunay triangulation. The library also have several functionalities to extract 2D images from 3D data, that is particularly suitable for our applications since the reslice of the 3D volume was a desired functionality that most of the professionals in the area are used to.

Regarding Graphical User Interface (GUI), KWWidgets [KWWidgets] was used since it is provided by the same company (Kitware) as VTK, and supported by NAMIC [ITK] (National Alliance for Medical Image Computing), reducing future problems of integration between the 2 libraries. KWWidget is a free multi-platform open source library with several GUI classes based on Tcl/Tk with a wrapper for C++ interface.

The medical format we use is Analyze: one of the most popular in the neurological imagiology field. Another advantage is that it is common to a large variety of exams: CT, MRI and SPECT for example.

3.2 Implemented Functionalities

3.2.1 Image Importation

The importation of the Analyze format [Analyze] proved to be fast and easy. The data is divided in two files: a header file that contains all the relevant information about the image (eg. dimension, spacing, patient related data). The other file is the uncompressed raw data of the image.

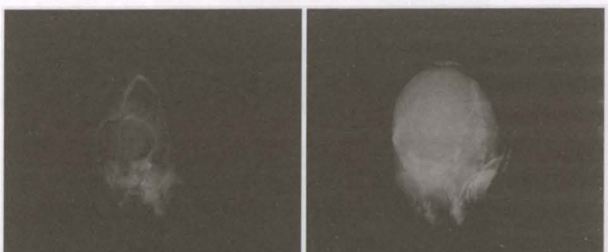

Figure 2 - Volume Rendering of CT (left) and MRI (right)

3.2.2 2D and 3D Visualization

In a preliminary version, some trials with iso-contours have been done, but with a volume rendering algorithm, when using a proper color transfer function, gives a much more detailed information about the internal structures of the brain. The final VTK pipeline used, also includes a class to resample the data, to speed up the processing during the manipulation of the data. It is possible to load at the same time, a 2D template of the electrode's grid, as well as the 3D positions of the electrodes detected from the CT data, displayed with the MRI volume. At this time, The CT/MRI registration is done using external tools (SPM) but we plan to integrate this functionality in future evolutions of the software.

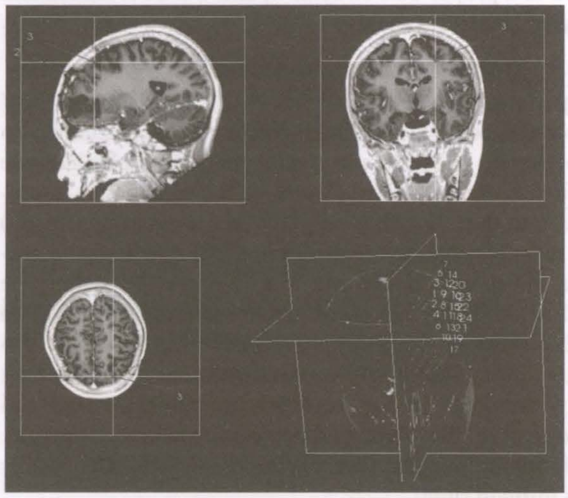

Figure 3 - 2D slice views and 3D view of a CT.

Besides the 3D visualization, a vtkImagePlaneWidget was used to cut the 3D volume in the axial, coronal and sagital axes providing for each one a slice that can be seen in the final interface as presented in Figure 3.

3.2.3 Extraction of the position of Electrodes

The automatic extraction of the position of the electrodes within the brain is done based on the CT images acquired with the electrodes grid in place. Since the electrodes are metallic, they appear with very high values when compared with tissues or bones. A simple algorithm was applied to extract the location of the electrode by thresholding the CT data and then computing the center of gravity of the several blobs coming from the thresholding. Since the algorithm is computationally intensive, the user can interactively adjust the threshold at the beginning to ensure that the relevant information is filtered. The centres of gravity of the filtered regions are then found using a vtkImageSeedConnectivityFilter.

At the end of this process the locations of the electrodes are visualized within the pre-registered MRI (see Figure 2). In this phase, the user can easily remove wrong or misaligned electrodes with a mouse click.

3.2.4 Electrode mapping and association of contextual information

In the final application, it is possible to load at the same time a 2D template of the grid of electrodes (lower left of Figure 5) as well as the 3D position of the electrodes detected from the CT data. The electrodes are presented in 3D the same window as the MRI (lower left of Figure 5) as red spheres. It is then possible to associate context information between the 2D template and the 3D position of the electrodes.

This association is performed through several picking callbacks associated with the 3D, 2D visualization and the display of the template grid. The user can associate each electrode to a functional area: language, memory, motor, seizure start or propagation. This information is saved in a proper data structures, and can be reloaded and updated later if necessary.

3.2.5 Spatio-temporal visualization of electrical activity

Another functionality of our software is its possibility to map directly in 3D the electrical activity in each electrode through color mapping. First a polygonal model is created from the 2D grid (using 2D Delaunay triangulation) and mapped into the 3D position of the electrodes to create a 3D model of the grid that is displayed within the MRI data. Finally electrical activity is mapped through a lookup table in the polygonal model. The user can also follow the evolution of the electrical activity along time using two keys of the keyboard to move forward and backward in the electrical data mapped over the grid. With this option, the data of the ECoG and MRI can be seen through time.

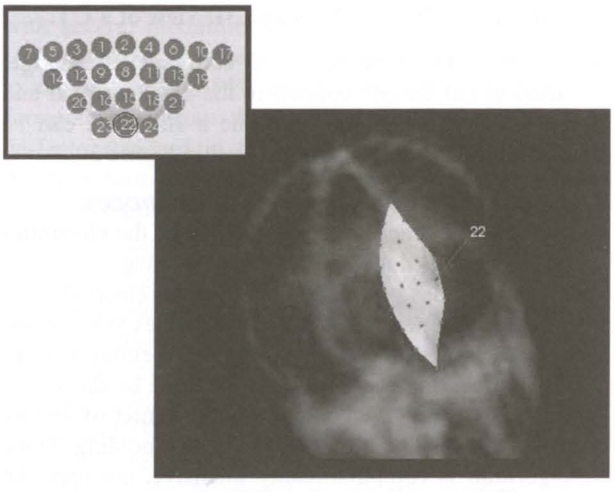

Figure 4 - Electrical data mapped both in the electrode grid and 3D model .

4. FINAL APPLICATION

The final application is divided in two, one for electrode extraction and the other for visualization and manipulation of the data. In the first application, the user is able to select the CT image file from witch he wants to extract the electrodes. He can correct the dimension and spacing values automatically read from the Analyze header, preview the interval for the threshold filter and then run the algorithm to find the center of gravity of the several blobs. Here the application may take some time, each new center detected is displayed in a log box.

When all the points are detected, a CT original volume is then displayed with spheres drawn on the correspondent positions. The user selects, the ones that are electrodes, and may select a file to save the electrode positions.

In the application for the visualization and manipulation of the data, the user is able to select the medical image file, and the file with the electrode positions. He can also correct dimensions and spacings.

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The final interface is divided in the three 2D views (axial, coronal and sagital views) (B, C, D), the 3D view (A) and the tabbed toolbar (H). The user can rotate, pan and zoom the 3D view using the mouse, he can also zoom using the preset zoom buttons in the toolbar (H - Sync). He can use the sliders to navigate through slices, or move the planes in the 3D view. The user can also click in any point of the 2D views and the other will automatically align the others. Also by clicking in the electrodes in the 3D view, all the 2D views will align.

The user can select a template electrode grid (I) and if the electrodes of the template grid have not already been mapped with the extracted ones. The user can map then, enabling the mapping mode (I), and by clicking in each electrode and selecting in the combobox the correct extracted electrode. The user can navigate through the electrodes using the arrows (J), or by clicking in the grid view (E). Different labels can be set for each electrode (F) that correspond to different colors. Label and color data can be saved (H), this data can be loaded latter as a grid template. The file with the electrical data can be loaded (H) to display the ECoG data (G and E). The user can use the keyboard to navigate the electrical data through time.

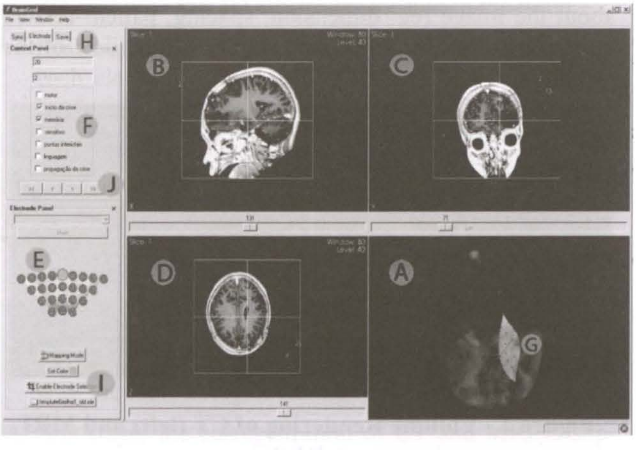

Figure 5 - Final Interface, showing MRI, both 2D and 3D, template grid and electrical data in 3D and electrode template grid view.

5. CONCLUSION

As a proof of concept, we were able to support the overall process needed for the ECoG - MRI co-registration: electrode extraction, mapping electrodes to ECoG measurements, combined visualization of both data in 2D and 3D. The implemented tool supports the visualization of multiple sources of information (MRI, CT, ECoG) based on a simple interface as initially devised.

In order to transform the present software tool in an effective clinical application several several steps are planned: include improvements on electrode extraction, integration of co-registration method in the tool and tune the tool user interface.

The current algorithm of ECoG electrodes extraction still needs improvements. Our first approach can be optimized in order to reduce the computational time and to improve the accuracy. Second, the problem of dealling with more than one grid of electrodes must be dealt with as in more complex cases this is a common practice.

The integration of a co-registration method is relevant. We plan to integrate the co-registration methods implemented in the Insight Segmentation and Registration Toolkit (ITK) methods [ITK], to avoid the resource to external tools such as SPM. In the midst of several freely available existant implementations ITK) appears to be ideal option as it provides both the state-of-the-art methods and allows an easy integration with both VTK and KWwidgets.

Further evolutions are planned with the end-users in more realistic usage of the tool in order to trim and adapt it to a realistic clinical environment in the epilepsy surgery program in the HUC, Coimbra.

6. ACKNOWLEDGMENTS

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