EEG/MEG Propagating Dipole Source Estimation

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Background

The framework of this project is the so-called brain topography. The main purpose of brain topography is to map the internal structure of the brain and to localize areas of certain function or dysfunction using non-invasive measurement techniques [1].

Over the last two decades structural imaging techniques, X-ray computer tomography (CT) and magnetic resonance tomography (MRT), have became precise enough to depict the brain with a resolution of roughly one millimeter.

Non-invasive techniques are based on the record the electric and/or magnetic activity at the surface of the head. Berger performed the measurement of small potential differences at the scalp in 1924 [2]. Such a registration is called an electroencephalogram and it became routine clinical practice. Currents inside the brain generate those potential differences. Since any current also generates a magnetic field, it should be theoretically possible to measure the magnetic field outside of the head. Because very sensitive sensors are needed to measure this field, it was not possible to do so until the development of the so-called superconducting quantum interference device (SQUID). The registration of the brain magnetic activity, a magnetoencephalograpm, was first carried out successfully by Cohen in 1968 [3].

Electroencephalography (EEG) and magnetoencephalography (MEG) are the only two methods to study the functional organization of the brain with a temporal resolution of 1 ms. This unique feature seems to be useful to measure with enough precision propagating activity on the cortex. Moreover, these methods are complementary rather than competitive as mathematically argued by Muravchik and Nehorai in [4].

Brain topographic analysis involves, apart from the measuring techniques, concepts from digital signal processing, numerical and statistical analysis, physics of electric and magnetic fields, computer simulation, and computer graphics and cartography.

An example of application of brain topography is the treatment of patients suffering from temporal lobe epilepsy (TLE), in which anti-epileptic drug treatment fails [5]. Seizures, with loss of conscience, may occur in such patients even many times a day, and thus severely hamper social functioning. These patients are candidates for epilepsy surgery. When considering surgery, it is important that the location of the epileptic focus is well determined beforehand. This focus is the source of spontaneous interictal EEG and MEG activity known as interictal spikes. The location of the origin of such spikes may be considered an index of the cortical area from which seizures originate [6].

Because EEG /MEG measures are taken on or above the surface of the head, these measurements are not a direct representation of the distribution of the activity on the cortex. This is an inverse problem with non-unique solution [7]. Therefore, models of the head and the source of activity are needed [8] to project the characteristics of activity at the cortex out of the measured data.

The head is often modeled as a conducting region of space, in which the conductivity changes with the various types of tissue (i.e., the scalp, the skull, the brain, and the fluids surrounding the brain and other tissues). A compartment model delineates the head where each compartment has its own electrical conductivity. In simplified models, the compartments are described by a set of concentric spheres [9]. To improve the accuracy of the inverse solution, more realistically shaped multicompartment models of the head can be used [4], which can be generated from the MRI scans.

The concept of hypothetical sources is a powerful tool for topographic analysis. This approach considers that active neuronal aggregates can be approximated by discrete sources, each capable of generating a portion or component of the final signal that is manifest at the scalp. A common model for the sources is an equivalent current dipole (ECD). The ECD may be stationary during the measurement procedure or more generally, it can be propagating and varying during the measuring stage depending of the particular brain function being studied.

It can be assumed that one or more dipoles are at a fixed position during a given time-interval and that their strength and orientation varies over time. This is the so-called fixed dipole model.

A different approach is to allow the dipoles to change their position as well as their strength and orientation. Basically, this method fits one or more dipoles at each time-instant independently. This is the moving dipole model [10, 11].

A third approach is to try and estimate current distributions in the brain [12]. Basically, the result of this method is a fixed dipole solution with many fixed dipoles at discretized points in the region of interest.

A fourth approach, that we are proposing and developing, is the dynamic or propagating dipole model [13, 14]. The moving dipole model can estimate the instantaneous parameters of a propagating ECD as a function of time for each sample separately, as if the source was stationary. In our work, it is conjectured that the parameter's evolution is better described by the trajectory of a dynamic model given by a set of known difference equations. The approach presented in [13] is based on a deterministic description of dipole trajectories. In [14] we introduce the use of a linear dynamic stochastic model to describe the trajectories, and we use simulated trajectories motivated in studies of auditory evoked responses [15].

Objectives

There is ongoing research collaboration between Professors Arye Nehorai of the Electrical Engineering and Computer Science Department of the University of Illinois at Chicago (UIC) and Carlos Muravchik of the Dpto. Electrotecnia Universidad Nacional de La Plata (UNLP) in the subject of statistical processing of EEG/MEG signals. Some of the results of this collaboration on the achievable precision in localization of sources with a realistic head model are [4], [14].

In the frame of the cited collaboration, Oscar Bria is pursuing a Doctor's degree at La Plata University under the guidance of Doctor Carlos Muravchik. The main topic of his degree research is precisely Performance Evaluation and Techniques for EEG/MEG Estimation of Propagating Dipole Sources.

The objectives of the present project are: i) to develop a method to jointly estimate the parameters of the dipoles and of the linear stochastic model, and ii) to calculate the precision that could be obtained when estimating the parameters of a finite number of propagating dipoles, including an unknown linear dynamical model.

Methodology

Our previous work [11] dealt with computation of the Cramér-Rao bounds on the estimation accuracy of the dipoles' locations, with a realistic head model and a linear dynamic stochastic model whose parameters are assumed to be known.

We will work towards our objective with the following activities during 2000 and the beginning of 2001:

1. Choice and review of techniques useful for extending our previous work. Among them are dynamic models with unknown parameters, extended Kalman filtering for uncertain plants, and techniques for tracking.

2. Simulation of realistic head and source models for testing the estimation techniques.

3. Derivation of the Cramér-Rao lower bound on the error of estimating the parameters of a dynamic ECD source with unknown dynamics and a realistic head model. Lower bounds give an indication of performance limitations and consequently they can be used, among other applications, to determine whether imposed performance requirements are realistic or not. We will use results of [11] and [16].

4. Derivation of an estimation procedure for ECD propagating sources based on a robust

extended Kalman filtering model for uncertain models. The estimation procedure has to produce estimates of six parameters (three for position and three for orientation) for each dipole for any snapshot of time, plus the parameters of the underlying dynamic model during the hole period of observation. We will use results for the estimation of stochastic dynamical systems [3] and for the tracking of multiple moving sources [14].

5. Simulations for testing the proposed estimation procedure for representative sources, using data of an actual EEG/MEG system and a realistic head model.
6. Publish the results and conclusions in international journals and conferences.

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