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BRAIN SOURCE IMAGING: REQUIREMENTS AND PERFORMANCE ESTIMATIONS

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Abstract

The bioelectrical imaging of the brain requires a good spatial resolution (few millimeters), high temporal and frequency-domain resolution, while preserving some conventional services (like visualization of 10-20 EEG leads). Additionally, in longitudinal studies the reproducibility of the source localizations is also essential. According to our simplified simulation results an EEG SNR of 20dB or above and geometry-related errors under 1mm are required to achieve the requested spatial resolution.

1. Introduction

During the last couple of years, brain electro- and magnetic mapping (BEM) based source imaging has emerged as a supplement to other neuroimaging modalities like fMRI, PET [1-4]. This field is still under an intensive development, but it is expected to become a cost-effective new modality with acceptable spatial resolution and long-term reproducibility and excellent (0.5-1 msec) temporal resolution [5-6]. Cost-effectiveness should have significance when slowly varying phenomena e.g. brain plasticity in recovery from stroke has to be studied longitudinally.

The main objective of this study was a theoretical and practical investigation of the parameters primarily responsible for spatial resolution and reproducibility.

2. Data acquisition: System overview

Some details of the government-founded NKFP project (NKTH grant # 2/004/04, Budapest, Hungary) at the University of Pannonia for creating a new brain electro-mapping (BEM) modality for neurological research including the longitudinal investigation of brain plasticity is summarized in Table 1.

Table 1. Major components of the BEM system

BEM hardware	Shielded room, 128-channel BioSemi ActiveTwo data-acquisition unit, headcaps, auxiliary EMG, EOG and finger-tapping marker channels, Zebris electrode position localizer
Auxiliary modality	MRI, fMRI
BEM software	Artifact rejection, time-aligned averaging, 10-20 lead visualization, topographic scalp potential and surface Laplacian map display, topographic short-time Fourier transform display.
Volume conductor modeling	4-layer spherical model, Package for real patient's volume conductor geometry determination.
Additional units	Transcranial magnetic stimulator (TMS)

The observation of the slow post stroke brain plasticity phenomena requires reproducible longitudinal measurements in several sessions while multi-lead EEG records are taken [2]. In each session the averaged finger-tapping response was selected for this purpose: the patient is to click a button with the index finger of the selected hand at a pace determined by the test protocol. For the purpose of synchronized averaging minimum 30-100 clicks are required with a repetition interval of a few seconds.

3. Resolution and reproducibility estimates

The four-layer spherical head model describing brain activity as dipole activations has been chosen for our performance estimates (Figure 1.). The model is characterized by the Poisson equation which is a quasi-stationary approximation of the Maxwell equations.

Using the analytical forward solution for calculating scalp potential distribution (EEG) of cortical or deeper-lying equivalent dipole sources, it is possible to accomplish the inverse of this calculation. Furthermore, it is possible to quantify the approximate impact of measurement noise and/or inaccurate volume conductor parameters (geometrical or conductivity) on the spatial resolution. In a more advanced stage of the development the tests outlined will be repeated on realistic volume conductor models.

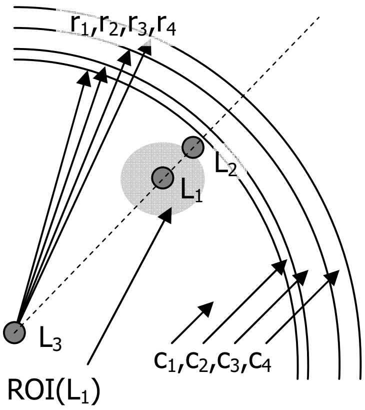

Figure 1. Four-layer spherical model of the human head with the test-source and ROI locations

By reducing the highly ill-posed inverse solution's search space to only one dipole (using signal separation methods like the Independent Component Analysis), this inverse process is reduced to a search of the brain area for the best fitting dipole (the subspace has 6 degrees of freedom: 3 coordinates for location and 3 coordinates for orientation). Multiple search algorithms are being developed and tested for efficiency: Genetic Algorithm based, Monte Carlo methods and full walk of possible solutions.

4. Results and Discussion

The evaluation of dipole localization errors has shown and proven what has already been predicted: geometry-related errors (volume conductor and electrode location uncertainties) are more severe than errors originating from EEG signal noise and false tissue conductivity presumptions [5-6].

According to our simulation study the additive effects of error factors produce an acceptable spatial resolution (under 2 millimeters) with an EEG SNR of 20dB, 1 mm volume conductor geometry- and 1 mm of electrode location errors with an error of 10% in conductivity values.

According to our measurements, currently the Zebris ultra-sound 3D measuring system does not allow reproducible EEG electrode positioning within the accuracy range required (see Figure 2. where the same EEG electrode arrangement was measured twice; red dots show first measurement, yellow dots second measurement).

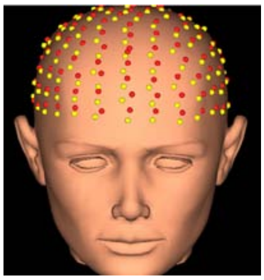

Figure 2. Electrode position measurements by the Zebris electrode localizer

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