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An attempt to localize brain electrical activity sources using EEG with limited number of electrodes

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ABSTRACT

A very interesting research goal is to find underlying sources generating the EEG signal – referred to as the ''EEG inverse problem''. Its aim is to determine spatial distribution of brain activity, described by local brain currents density, on the basis of potentials measured on the scalp as EEG signal. The purpose of the research presented in the article was to check whether the results of the inverse problem solution, obtained by the LORETA algorithm for the reduced set of 8 electrodes selected by the authors will be close to the results for the initial set of 32 electrodes. EEG signals were registered during the BCI operation based on ERD/ERS potentials. Obtained results showed no significant differences in the location of the most important sources in both cases. It is worth emphasizing that reducing the number of electrodes would have a significant impact on an BCI ergonomics.

1. Introduction

Advanced studies of EEG signals led to discovery of properties and rules that enable us to identify specific EEG components evoked by particular stimuli. It was also found that specific components appear not only in the event of a real stimulus, but also in a case of a so-called ''mental task'', when somebody thinks about doing a particular movement (movement imagining). Detection of this activity may form the basis for constructing asynchronous brain–computer interfaces (BCI) – ''control by thoughts''.

It is worth pointing out that different areas of the brain are active when a person imagines movement of different body parts, like hand, leg, feet or tongue. When analyzing EEG signals evoked by imagining movement this is referred to as desynchronization and synchronization of brain potentials associated with these intentions (event-related desynchronization/synchronization – ERD/ERS) [1].

Cortical areas connected with hands, feet and tongue are characterized by pretty large topographical differences. Therefore, those body parts are usually used as subjects of movement imagination in BCIs. But selecting the number of electrodes as well as the right placement of electrodes on the

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scalp, in that case, is still not a trivial task [2]. Solving the so called inverse problem can be helpful in the selection process.

The objective of the EEG inverse problem is to determine spatial distribution of brain electrical activity, described by brain currents density, on the basis of potentials measured on the scalp. In a simplified model, the sources are considered to be current dipoles distributed across different regions of the brain. Current dipoles are used to model neuronal sources of electromagnetic fields causing voltage potentials measured on the scalp as EEG signals. It should be taken into account that there is an infinite number of different configurations of these sources which generate the same distribution of potentials on the surface of the skull. This means that the inverse problem is *ill-posed* and its solution is not unique. It is difficult to decide which source configuration is the most accurate given the EEG data.

The main objective of our experiment was to check whether the results of the inverse problem solution, obtained by the LORETA (Low Resolution Brain Electromagnetic Tomography) algorithm, will be similar for the set of 8 electrodes selected by the authors and initial set of 32 electrodes. EEG signals were registered during the BCI operation based on ERD/ERS potentials for which signal sources are located in the cerebral cortex, at a very small depth [1]. Limiting the number of electrodes is very important and has a significant impact on the ergonomics of brain-computer interface [3,4].

2. *Solving the inverse problem – the LORETA algorithm*

The solution to the inverse problem lies in finding the location of brain electrical activity sources described by current density, directly on the basis of the potentials distribution φ on the scalp (Fig. 1). This problem is described by the general formula [5]:

$$\hat{J} = K^{-1} \cdot \varphi \quad (1)$$

where K, transformation (transition) matrix with dimensions $n_e \times (3n_v)$; n_e, number of electrodes, n_v, number of voxels, for which the estimate of current density $\hat{J}$ is sought.

The best estimation of the density distribution is found by assuming the distribution of J and repeatedly solving the so-called forward problem [5]:

$$\varphi = K \cdot J \quad (2)$$

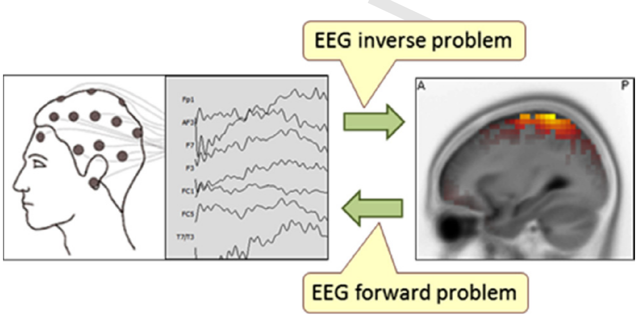

Fig. 1 – The concept of EEG forward and inverse problems.

In order to calculate the current density distribution in the brain a certain model needs to be adopted, representing the activity of a larger group of neurons, in the form of local dipole, quadrupole, or even larger structures like a dipole layer. Individual fractions of neurons of the cerebral cortex have their specific contribution to the potential distribution on the surface of the head – therefore, these structures are generally referred to as "sources of EEG signals." The inverse problem comes down to finding the location of sources of these partial activities or otherwise location of the "EEG generators."

One of the main problems encountered while solving both, forward and inverse problems, is finding the transformation (transition) matrix **K**. In practice, it is calculated using the basic laws of electricity, such as the principle of charge conservation and the Maxwell's law, assuming certain boundary conditions. Until now, head models have been usually approximated with a sphere. For more realistic head models either the data taken from the Atlas of the human brain or individual data acquired for example by computed tomography (CT) or magnetic resonance imaging (MRI) are used [6]. Then different assumptions concerning for example (non)uniformity and (an)isotropy of the conductivity distribution in various parts of the brain need to be taken into account.

The difficulty in calculating electrical activity of the human brain, based on the EEG time series derives not only from the sheer complexity of its structure (the model may be always more or less simplified), but from the fact, that the number of voxels is significantly greater than the number of electrodes ($3n_v >> n_e$). As it was mentioned above, the inverse problem is *ill-posed*, so there is an infinite number of different configurations of "EEG generators" that result in the same potential distribution across the surface of the skull. Further assumptions of mathematical, neuroanatomical and/or neurophysiological nature are required for explicit identification of the location of electrical sources that produce the measured EEG.

There are many methods of locating the EEG sources. They are different in the way of how dipoles are modelled, additional criteria (constraints) formulated and optimization algorithms used [7]. They can be divided into:

- parametric methods whereby the activity of the brain is modeled by a small number of individual current dipoles (equivalent current dipole – ECD approach),
- nonparametric methods whereby electrical brain activity is modeled by so-called distributed sources (linear distributed – LD approach).

Dedicated computational methods for solving the EEG inverse problem are based on nonlinear optimization algorithms (e.g. *minimum norm estimates and their generalization*) and spatial scanning and beamforming approaches. Artificial intelligence, especially neural networks and genetic algorithms are still popular.

In another approach, the so-called distributed sources are used – DSR (distributed-source reconstruction) to solve the EEG inverse problem. In this case the number of "generators" and their orientation are not taken into account. Instead, the current density distribution is searched in the space of all possible solutions.

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