Reconstruction of Low Frequency Currents

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***Abstract*—Non-invasive functional localization of normal and pathological function of the brain or the heart is a major goal in bioelectromagnetic research. Numerous inverse techniques are used to achieve this goal. We build a realistically shaped human body phantom for experimental verification of these inverse solution techniques which are applied to magnetic (and electric) measurement data. Inside the phantom dipolar and extended physical sources are used to generate the fields. Magnetic field maps close to the phantom surface were recorded with the help of SQUID-based sensors, and body surface potential maps (BSPM) were recorded by means of surface electrodes. These data can be used to evaluate inverse techniques applied in bioelectromagnetics and other fields of research.**

I. INTRODUCTION

BIOMAGNETIC measurements provide non-invasively information about the electrical active organs, like the heart or the brain. The diagnostic use of this information often requires the solution of inverse problems. Inverse solution strategies for the reconstruction of focal and extended current sources within realistically shaped volume conductors are one of the main research topics in bioelectromagnetics [1]. The estimation of current density distributions using reliable and stable source reconstruction techniques is a vital problem in clinical diagnosis [2].

In order to validate different inverse algorithms, a physical torso phantom including models of extended current sources has been developed. Measurements of magnetic field maps and surface potential maps can be performed at several biomagnetic centers all over the world where magnetically shielded rooms and multi-channel biomagnetometer systems are available. We use the facilities of the Biomagnetic Center of the Friedrich-Schiller-University of Jena [3].

The majority of the source reconstruction methods currently used are designed for localization of single current dipoles or small sets of dipoles. Therefore, the main goals of this proposal are:

1. Validation of inverse methods applied to the biomagnetic inverse problem of extended sources.
2. Comparison of the efficiency of different inverse methods applied to the reconstruction of given extended sources (current density distributions).

II. METHODS

A. Phantom Modeling

The torso phantom is based on a copy of the body surface of an adult male volunteer (Fig.1). The phantom was made of a non-magnetic epoxy resin to avoid an additional source of noise. The phantom was filled with a 0.9 % saline solution corresponding to a volume conductor conductivity of 1.44 S/m. Inside the phantom current sources can be mounted in exactly known positions [5].

Fig. 1. Human body phantom (frontal view) with surface electrodes.

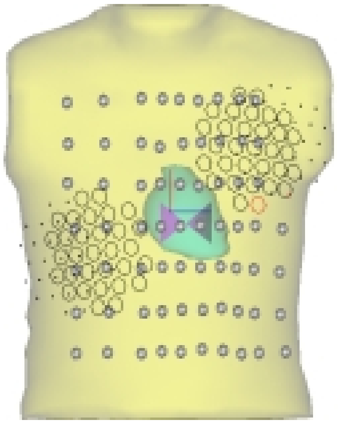

Fig. 2. Phantom surface including an extended current source model, with 67 surface electrodes and preferred position of the 2x31 magnetic sensors.

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B. Source Modeling

An extended physical source suitable for magnetic measurements was constructed by enlarging the tips of a dipole into rectangular electrodes with total dimension of 50 mm x 60 mm (Fig. 3).

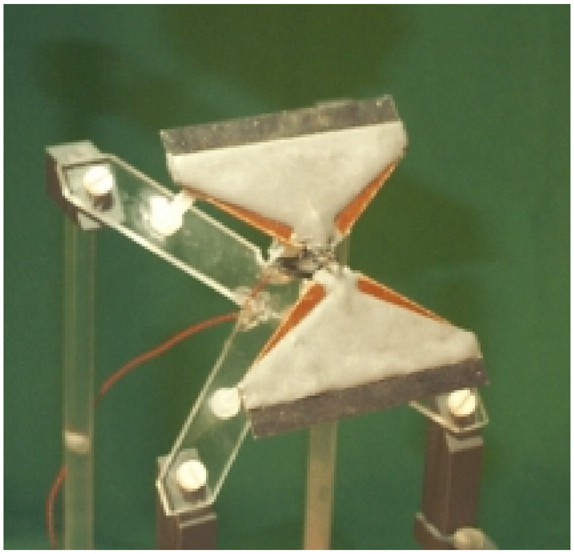

Fig. 3. The extended current source model, mounted on a plastic stand for precise positioning inside the phantom.

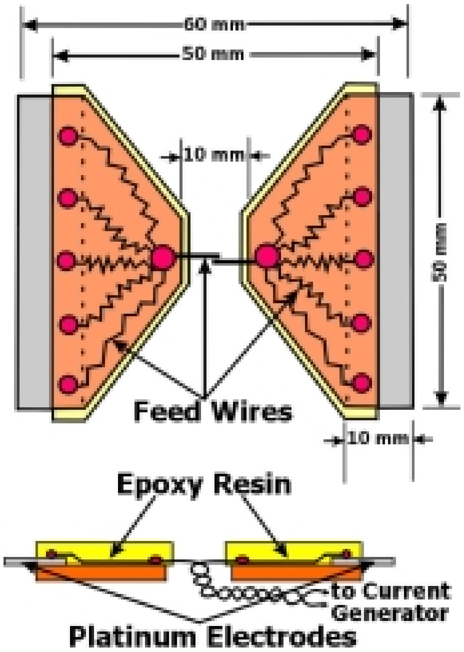

Fig. 4. Layout of the extended current source model used for biomagnetic phantom measurements.

We have used platinum electrodes (thickness 0.2 mm) and an impressed current of 500 µA (peak-to-peak) with a frequency of 25 Hz which is applied to the electrodes by means of twisted feed wires. Due to the connection of several wires with identical resistances to both rectangular platinum electrodes (size 10 mm x 50 mm) a homogeneous current density across the electrode lengths can be assumed. The electrodes and feed wires are mounted on trapezoidal Pertinax sheets (thickness 1 mm) which are finally covered by epoxy resin (thickness about 1 mm) to guarantee electric insulation (Fig. 4).

C. Measurements

Measurements were performed using a twin dewar biomagnetometer system (Philips Research, Hamburg, Germany) with 2 x 31 channels operating inside a magnetically shielded room (AK3b, Vacuumschmelze, Hanau, Germany). The symmetrical first-order axial gradiometers have a coil diameter of 2.0 cm and a base length of 7 cm [6]. Both the pick-up coil and the compensation coil have two turns of niobium wire wound around a common fiber-reinforced epoxy cylinder. The imbalance of the gradiometers is less than 0.1%. The gradiometers are galvanically coupled to the SQUIDs. The field noise of the system is less than 10 fT /Hz$^{-1/2}$ at 1 Hz [7]. Data were acquired by commercially available EEG amplifiers (SynAmps, Neuroscan, USA). The unipolar electric potential measurements were referenced to the right arm electrode. It is recommended to use common average reference (CAR) in source localization procedures based on BSPM data. The magnetically measured quantity is the magnetic flux density normal to the pick-up coil of each gradiometer which is due to the coil extension (diameter of 20 mm) a sum signal. Additionally, 64 channels of ECG were recorded simultaneously (SynAmps). The position of the dewars in relation to each other and to the phantom was obtained by localizing ten small magnetic markers. Each marker consists of three coils perpendicular to each other, thus giving independence from the orientation of the coil triplet [8].

III. THE INVERSE PROBLEM

Inverse solutions can be performed using magnetic field and/or electrical potential measurements [4,5]. Commonly, the combined use of electric and magnetic data in source reconstruction procedures is achieved by transforming both signal types into the signal-to-noise space.

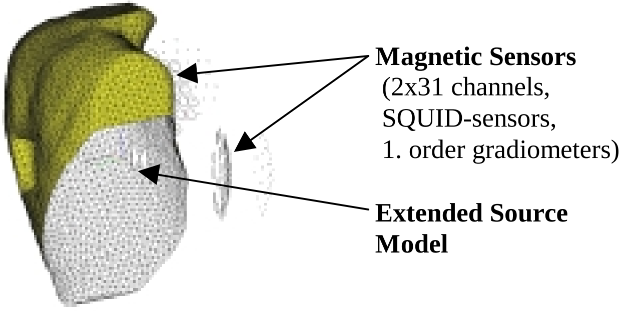

Fig. 5. The biomagnetic inverse problem: reconstruction of an current density distribution generated by an extended current source inside a volume conductor using external magnetic field measurements and surface potential measurements, respectively.

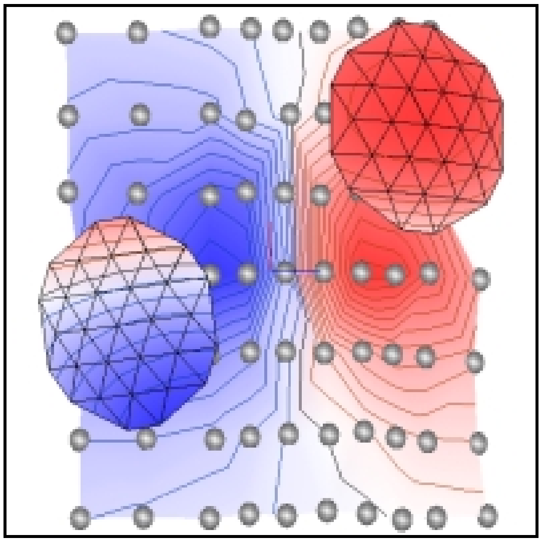

Fig. 6. Measured magnetic field and electric potential distribution generated by the extended current source of Fig. 4 in the body phantom.

We used the phantom measurements to verify source reconstruction techniques (see Fig. 6). Different minimum norm estimations were applied to both magnetic and electric data. But in our experience it is very difficult or almost impossible to estimate the real extension of the original current distribution in space, even if all available a priori information was taken into account [5,9,3].

The application of the phantom measurements is not constrained to biomagnetism. Very similar inverse problems appear in other disciplines, for instance in nondestructive evaluation (NDE), electrical impedance tomography (EIT), or in environmental electromagnetic compatibility (EMC).

The well-known measurement conditions and the precisely known geometric configuration of the volume conductor and the current source allow an evaluation of different optimization techniques. Therefore, the ultimate goal of this TEAM problem proposal is the improvement and/or new development of optimization strategies for the reconstruction of current density distributions in 3D space.

The complete measuring data sets including MRI data, gradiometer files, electrode positions (and a BEM model of the phantom) are available on our Web page:

http://www.biomag.uni-jena.de/romeo.htm.

Furthermore, reprints of the literature cited are available upon request from the authors of this paper.

IV. REFERENCES

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