Electromagnetic Inverse Problems in Biomedical Applications

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Source reconstruction is a widely used method to estimate the location, orientation, and strength of bioelectrical sources from surface potential measurements or from magnetic field measurements. In particular, it is extensively used in the localization of neuronal activity in the brain, but it is also used to localize electrophysiological activity in the heart and in other biomedical research areas. Source reconstruction comprises the computation of bioelectric and biomagnetic fields due to given sources (the forward problem) and the source parameter estimation based on given measurements (the inverse problem). The presentation is organized in main four sections which will cover measurement techniques, the forward problem, the inverse problem, and validation approaches.

In the first section, the underlying measurement techniques are briefly reviewed, where emphasis is set to magnetoencephalography (MEG), magnetocardiography (MCG) and magnetic marker monitoring (MMM). Since biomagnetic fields commonly are very small with respect to urban or environmental fields, advanced noise cancelation techniques are required. In the second section, the forward problem in MEG is considered. It involves a model with the conductivities of the head, which can be as simple as a homogeneously conducting sphere or as complex as a finite element model consisting of millions of elements, each with a different anisotropic conductivity tensor. In the third section, an example for a biomedical inverse problem is discussed: the optimization of cardiomagnetic sensor distributions. In MCG, often the distribution of currents in the heart is of interest. Currently, the cardiomagnetic fields are recorded with superconducting quantum interference devices (SQUIDs), which are restricted to the inside of a cryostat filled with liquid helium or nitrogen. New room temperature optical magnetometers allow less restrictive sensor positioning, which raises the question of how to optimally place the sensors for robust field reconstruction. In the fourth section, results from three validation approaches are presented: simulations, phantom measurements, and animal measurements.