Preface

Neuronal activities in a human brain generate coherent synaptic and intracellular currents in cortical columns, which generate electric potentials on the scalp surface and magnetic fields outside the head. Electroencephalography (EEG) measures these potentials and magnetoencephalography (MEG) measures these magnetic fields to obtain information on the state of the brain. The class of methodologies that reconstruct and visualize the neuronal activities based on MEG/EEG sensor measurements is referred to as the electromagnetic brain imaging.

In the past two decades there have been significant advances in signal processing and source reconstruction algorithms used in electromagnetic brain imaging. However, electromagnetic brain imaging can still be considered a young field. This is primarily due to the complexity associated with the electrophysiological brain activity underlying the signals. Also, it is true that applying the electromagnetic brain imaging with confidence requires an understanding of the relevant mathematics, physics, biology, and engineering as well as a broad perspective on human brain science. Due to its interdisciplinary nature, such a broad knowledge base takes years to acquire.

This book is intended to provide a coherent introduction to the body of mainstream algorithms used in electromagnetic brain imaging, with specific emphasis on novel Bayesian algorithms that we have developed. It is intended as a graduate level textbook with the goal of helping readers more easily understand the literature in biomedical engineering and in related fields, and be ready to pursue research in either the engineering or the neuroscientific aspects of electromagnetic brain imaging. We hope that this textbook will not only appeal to graduate students but all scientists and engineers engaged in research on electromagnetic brain imaging.

This book begins with an introductory overview of electromagnetic brain imaging in Chap. 1 and then discusses dominant algorithms that are used in electromagnetic brain imaging in Chaps. 2–4. Minimum-norm-based methods, which are classic algorithms and still widely used in this field, are described in Chap. 2, but with a Bayesian perspective in mind. Chapter 3 presents a concise review of adaptive beamformers, which have become a standard tool for analyzing brain spontaneous activity such as resting-state MEG data, and we also include a Bayesian perspective on adaptive beamformers.

Chapters 4–6 review Bayesian algorithms for electromagnetic brain imaging that we have developed in the past decade. Chapter 4 presents a novel Bayesian algorithm, called Champagne, which has been developed by our group. Since we believe that the Champagne algorithm is a powerful next-generation imaging algorithm, the derivation of the algorithm is presented in detail. Chapter 5 presents Bayesian factor analysis, which is a group of versatile algorithms used for denoising, interference suppression, and source localization. Chapter 6 describes a unified theoretical Bayesian framework, which provides insightful perspective into various source imaging methods and reveals similarities and equivalences between methods that appear to be very different.

Chapters 7–9 deal with newer topics that are currently in vogue in electromagnetic brain imaging—functional connectivity, causality, and cross-frequency coupling analyses. Chapter 7 reviews functional connectivity analysis using imaginary coherence. Chapter 8 provides a review of several directional measures that can detect causal coupling of brain activities. Chapter 9 presents novel empirical results showing that the phase-amplitude coupling can be detected using MEG source-space analysis, and demonstrates that the electromagnetic brain imaging holds great potential in elucidating the mechanisms of brain information processing. This chapter was contributed by Eiichi Okumura and Takashi Asakawa. The first two chapters in the Appendix provide concise explanations of bioelectromagnetic forward modeling and basics of Bayesian inference, and the third chapter provides supplementary mathematical arguments. These chapters are included for the reader's convenience.

Many people have made valuable contributions together with our own efforts in this area. Special mention must be made of Hagai Attias who is an invaluable collaborator. Hagai introduced us to probabilistic graphical models and Bayesian inference methods. He was an integral person in our fruitful collaboration, on which this book is based.

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We kindly ask readers to visit www.electromagneticbrainimaging.info. Supplementary information, as well as error corrections (if necessary), is uploaded to this website.

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