

Contents

1	Introduction to Electromagnetic Brain Imaging	1
1.1	Functional Brain Imaging and Bioelectromagnetic Measurements	1
1.2	Sensing Magnetic Fields from the Brain	2
1.3	Electromagnetic Brain Imaging	3
1.3.1	Forward Model	3
1.3.2	Inverse Algorithms	4
1.4	From Source Imaging to Functional Connectivity Imaging	6
1.5	Examples of Clinical Applications	6
1.5.1	Functional Mapping for Preoperative Neurosurgical Planning	6
1.5.2	Functional Connectivity Imaging	7
	References	8
2	Minimum-Norm-Based Source Imaging Algorithms	9
2.1	Introduction	9
2.2	Definitions	9
2.3	Sensor Lead Field	10
2.4	Voxel Source Model and Tomographic Source Reconstruction	11
2.5	Maximum Likelihood Principle and the Least-Squares Method	13
2.6	Derivation of the Minimum-Norm Solution	14
2.7	Properties of the Minimum-Norm Solution	15
2.8	L_2 -Regularized Minimum-Norm Solution	17
2.9	L_1 -Regularized Minimum-Norm Solution	19
2.9.1	L_1 -Norm Constraint	19
2.9.2	Intuitive Explanation for Sparsity	20
2.9.3	Problem with Source Orientation Estimation	23

2.10	Bayesian Derivation of the Minimum-Norm Method	24
2.10.1	Prior Probability Distribution and Cost Function	24
2.10.2	L_2 -Regularized Method	24
2.10.3	L_1 -Regularized Method	26
	References.	28
3	Adaptive Beamformers	29
3.1	Introduction and Basic Formulation.	29
3.2	Classical Derivation of Adaptive Beamformers	30
3.2.1	Minimum-Variance Beamformers with Unit-Gain Constraint	30
3.2.2	Minimum-Variance Beamformer with Array-Gain Constraint	31
3.2.3	Minimum-Variance Beamformer with Unit-Noise-Gain Constraint.	32
3.3	Semi-Bayesian Derivation of Adaptive Beamformers.	33
3.4	Diagonal-Loading and Bayesian Beamformers	35
3.5	Scalar Adaptive Beamformer with Unknown Source Orientation	36
3.5.1	Expressions for the Unit-Gain Constraint Beamformer.	36
3.5.2	Expressions for the Array-Gain and Weight-Normalized Beamformers	37
3.6	Vector-Type Adaptive Beamformer.	38
3.6.1	Vector Beamformer Formulation.	38
3.6.2	Semi-Bayesian Formulation	40
3.7	Narrow-Band Beamformer	42
3.7.1	Background	42
3.7.2	Time-Domain Implementation	42
3.7.3	Frequency-Domain Implementation	43
3.7.4	Five-Dimensional Brain Imaging.	44
3.8	Nonadaptive Spatial Filters.	44
3.8.1	Minimum-Norm Filter.	44
3.8.2	Weight-Normalized Minimum-Norm Filter.	46
3.8.3	sLORETA Filter.	46
3.9	Recursive Null-Steering (RENS) Beamformer.	47
3.9.1	Beamformer Obtained Based on Beam-Response Optimization	47
3.9.2	Derivation of RENS Beamformer	48
	References.	49
4	Sparse Bayesian (Champagne) Algorithm	51
4.1	Introduction	51
4.2	Probabilistic Model and Method Formulation	52

4.3	Cost Function for Marginal Likelihood Maximization	54
4.4	Update Equations for α	56
4.5	Modified Algorithm Integrating Interference Suppression	58
4.6	Convexity-Based Algorithm	59
4.6.1	Deriving an Alternative Cost Function	59
4.6.2	Update Equation for z	61
4.6.3	Update Equation for x_k	61
4.6.4	Update Equation for v	62
4.6.5	Summary of the Convexity-Based Algorithm	62
4.7	The Origin of the Sparsity	63
4.8	Extension to Include Source Vector Estimation	65
4.8.1	Update Equation for \mathbf{Z}_j	66
4.8.2	Update Equation for $\mathbf{s}_j(t_k)$	67
4.8.3	Update Equation for \mathbf{T}_j	68
4.9	Source Vector Estimation Using Hyperparameter Tying	69
4.10	Appendix to This Chapter	71
4.10.1	Derivation of Eq. (4.21)	71
4.10.2	Derivation of Eq. (4.29)	72
4.10.3	Proof of Eq. (4.50)	73
	References	74

5 Bayesian Factor Analysis: A Versatile Framework for Denoising, Interference Suppression, and Source Localization

5.1	Introduction	75
5.2	Bayesian Factor Analysis	75
5.2.1	Factor Analysis Model	75
5.2.2	Probability Model	76
5.2.3	EM Algorithm	77
5.2.4	Computation of Marginal Likelihood	79
5.2.5	Summary of the BFA Algorithm	81
5.3	Variational Bayes Factor Analysis (VBFA)	82
5.3.1	Prior Distribution for Mixing Matrix	82
5.3.2	Variational Bayes EM Algorithm (VBEM)	84
5.3.3	Computation of Free Energy	92
5.3.4	Summary of the VBFA Algorithm	95
5.4	Partitioned Factor Analysis (PFA)	96
5.4.1	Factor Analysis Model	96
5.4.2	Probability Model	97
5.4.3	VBEM Algorithm for PFA	97
5.4.4	Summary of the PFA Algorithm	100
5.5	Saketini: Source Localization Algorithm Based on the VBFA Model	101
5.5.1	Data Model	101

5.5.2	Probability Model	102
5.5.3	VBEM Algorithm	103
5.5.4	Summary of the Saketini Algorithm	107
5.6	Numerical Examples	107
5.7	Appendix to This Chapter	112
5.7.1	Proof of Eq. (5.84)	112
5.7.2	Proof of Eq. (5.94)	114
5.7.3	Proof of Eq. (5.103)	115
5.7.4	Proof of Eq. (5.166)	115
	References.	117
6	A Unified Bayesian Framework for MEG/EEG Source Imaging	119
6.1	Introduction	119
6.2	Bayesian Modeling Framework.	121
6.3	Bayesian Modeling Using General Gaussian Scale Mixtures and Arbitrary Covariance Components	122
6.3.1	The Generative Model.	122
6.3.2	Estimation and Inference	123
6.3.3	Source MAP or Penalized Likelihood Methods.	127
6.3.4	Variational Bayesian Approximation	131
6.4	Selection of Covariance Components C	133
6.5	Discussion	134
	References.	137
7	Source-Space Connectivity Analysis Using Imaginary Coherence	139
7.1	Introduction	139
7.2	Source-Space Coherence Imaging	140
7.3	Real and Imaginary Parts of Coherence	141
7.4	Effects of the Leakage.	143
7.4.1	Leakage Effects on the Magnitude Coherence.	143
7.4.2	Leakage Effects on the Imaginary Coherence	144
7.5	Corrected Imaginary Coherence	145
7.5.1	Modification of Imaginary Coherence	145
7.5.2	Factorization of Mutual Information	146
7.5.3	Residual Coherence.	148
7.5.4	Phase Dependence of the Corrected Imaginary Coherences	150
7.6	Canonical Coherence.	151
7.6.1	Canonical Magnitude Coherence.	151
7.6.2	Canonical Imaginary Coherence	154
7.6.3	Canonical Residual Coherence	157

7.6.4	Computing Coherence When Each Voxel has Multiple Time Courses	158
7.7	Envelope Correlation and Related Connectivity Metrics	159
7.7.1	Envelope Correlation	159
7.7.2	Residual Envelope Correlation	160
7.7.3	Envelope Coherence	160
7.8	Statistical Thresholding of Coherence Images	161
7.9	Mean Imaginary Coherence (MIC) Mapping	162
7.10	Numerical Examples	163
	References.	168
8	Estimation of Causal Networks: Source-Space Causality	
	Analysis	171
8.1	Introduction	171
8.2	Multivariate Vector Autoregressive (MVAR) Process	171
8.2.1	MVAR Modeling of Time Series	171
8.2.2	Coherence and Partial Coherence of the MVAR Process	173
8.3	Time-Domain Granger Causality.	174
8.3.1	Granger Causality for a Bivariate Process	174
8.3.2	Multivariate Granger Causality	175
8.3.3	Total Interdependence	177
8.4	Spectral Granger Causality: Geweke Measures	178
8.4.1	Basic Relationships in the Frequency Domain	178
8.4.2	Total Interdependence and Coherence	179
8.4.3	Deriving Causal Relationships in the Frequency Domain	180
8.5	Other MVAR-Modeling-Based Measures	182
8.5.1	Directed Transfer Function (DTF).	182
8.5.2	Relationship Between DTF and Coherence.	183
8.5.3	Partial Directed Coherence (PDC).	184
8.6	Transfer Entropy.	185
8.6.1	Definition	185
8.6.2	Transfer Entropy Under Gaussianity Assumption	186
8.6.3	Equivalence Between Transfer Entropy and Granger Causality	187
8.6.4	Computation of Transfer Entropy	188
8.7	Estimation of MVAR Coefficients	190
8.7.1	Least-Squares Algorithm	190
8.7.2	Sparse Bayesian (Champagne) Algorithm.	191
8.8	Numerical Examples	192
8.8.1	Experiments Using Bivariate Causal Time Series	192
8.8.2	Experiments Using Trivariate Causal Time Series	194
	References.	198

9	Detection of Phase–Amplitude Coupling in MEG Source Space: An Empirical Study	199
9.1	Introduction	199
9.2	Types of Cross-Frequency Coupling	200
9.3	Local PAC and Cross-Location PAC	201
9.4	Quantification of Phase–Amplitude Coupling	202
9.4.1	Instantaneous Amplitude and Phase	202
9.4.2	Amplitude–Phase Diagram	202
9.4.3	Modulation Index (MI)	203
9.4.4	Phase-Informed Time-Frequency Map	204
9.5	Source Space PAC Analysis: An Example Study	
	Using Hand-Motor MEG Data	204
9.5.1	Experimental Design and Recordings	204
9.5.2	Data Analysis	204
9.5.3	Results of Local PAC Analysis	206
9.5.4	Results of Analyzing Cross-Location PACs	209
9.6	Summary	212
	References	212
	Appendix A: Bioelectromagnetic Forward Modeling	215
	Appendix B: Basics of Bayesian Inference	231
	Appendix C: Supplementary Mathematical Arguments	247
	Index	267

Electromagnetic Brain Imaging

A Bayesian Perspective

Sekihara, K.; Nagarajan, S.S.

2015, XIV, 270 p. 32 illus., 27 illus. in color., Hardcover

ISBN: 978-3-319-14946-2