EEG SIGNAL PROCESSING

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Preface

There is ever-increasing global demand for more affordable and effective clinical and healthcare services. New techniques and equipment must therefore be developed to aid in the diagnosis, monitoring, and treatment of abnormalities and diseases of the human body. Biomedical signals (biosignals) in their manifold forms are rich information sources, which when appropriately processed have the potential to facilitate such advancements. In today's technology, such processing is very likely to be digital, as confirmed by the inclusion of digital signal processing concepts as core training in biomedical engineering degrees. Recent advancements in digital signal processing are expected to underpin key aspects of the future progress in biomedical research and technology, and it is the purpose of this research monograph to highlight this trend for the processing of measurements of brain activity, primarily electroencephalograms (EEGs).

Most of the concepts in multichannel EEG digital signal processing have their origin in distinct application areas such as communications engineering, seismics, speech and music signal processing, together with the processing of other physiological signals, such as electrocardiograms (ECGs). The particular topics in digital signal processing first explained in this research monograph include definitions; illustrations; time-domain, frequency-domain, and time-frequency domain processing; signal conditioning; signal transforms; linear and nonlinear filtering; chaos definition, evaluation, and measurement; certain classification algorithms; adaptive systems; independent component analysis; and multivariate autoregressive modelling. In addition, motivated by research in the field over the last two decades, techniques specifically related to EEG processing such as brain source localization, detection and classification of event related potentials, sleep signal analysis, seizure detection and prediction, together with brain–computer interfacing are comprehensively explained and, with the help of suitable graphs and (topographic) images, simulation results are provided to assess the efficacy of the methods.

Chapter 1 of this research monograph is a comprehensive biography of the history and generation of EEG signals, together with a discussion of their significance and diagnostic capability. Chapter 2 provides an in-depth introduction to the mathematical algorithms and tools commonly used in the processing of EEG signals. Most of these algorithms have only been recently developed by experts in the signal processing community and then applied to the analysis of EEG signals for various purposes. In Chapter 3, event-related potentials are explained and the schemes for their detection and classification are explored. Many neurological and psychiatric brain disorders are diagnosed and monitored using these techniques. Chapter 4 complements the previous chapter by specifically looking at the behaviour of EEG signals in patients suffering from epilepsy. Some very recent

methods in seizure prediction are demonstrated. This chapter concludes by opening up a new methodology in joint, or bimodal, EEG–fMRI analysis of epileptic seizure signals. Localization of brain source signals is next covered in Chapter 5. Traditional dipole methods are described and some very recent processing techniques such as blind source separation are briefly reviewed. In Chapter 6, the concepts developed for the analysis and description of EEG sleep recordings are summarized and the important parameters and terminologies are explained. Finally, in Chapter 7, one of the most important applications of the developed mathematical tools for processing of EEG signals, namely brain–computer interfacing, is explored and recent advancements are briefly explained. Results of the application of these algorithms are described.

In the treatment of various topics covered within this research monograph it is assumed that the reader has a background in the fundamentals of digital signal processing and wishes to focus on processing of EEGs. It is hoped that the concepts covered in each chapter provide a foundation for future research and development in the field.

In conclusion, we do wish to stress that in this book there is no attempt to challenge previous clinical or diagnostic knowledge. Instead, the tools and algorithms described in this book can, we believe, potentially enhance the significant clinically related information within EEG signals and thereby aid physicians and ultimately provide more cost-effective and efficient diagnostic tools.

Both authors wish to thank most sincerely our previous and current PhD students who have contributed so much to the material in this work and our understanding of the field. Special thanks to Min Jing, Tracey Lee, Kianoush Nazarpour, Leor Shoker, Loukianous Spyrou, and Wenwu Wang, who contributed to providing some of the illustrations. Finally, this book became truly possible due to spiritual support and encouragement of Maryam Zahabsaniei, Erfan Sanei, and Ideen Sanei.

Saeid Sanei
Jonathon Chambers
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List of Abbreviations

3D	Three-dimensional
ACT	Adaptive chirplet transform
AD	Alzheimer's disease
ADC	Analogue-to-digital converter
ADD	Attention deficit disorder
ADHD	Attention deficit hyperactivity disorder
AE	Approximate entropy
AEP	Audio evoked potential
Ag–AgCl	Silver–silver chloride
AIC	Akaike information criterion
ALF	Adaptive standardized LORETA/FOCUSS
ALS	Alternating least squares
AMDF	Average magnitude difference function
AMI	Average mutual information
ANN	Artificial neural network
AP	Action potential
APGARCH	Asymmetric power GARCH
AR	Autoregressive modelling
ARMA	Autoregressive moving average
ASDA	American Sleep Disorders Association
BCI	Brain–computer interfacing/interaction
BDS	Brock, Dechert, and Scheinkman
BEM	Boundary element method
BMI	Brain–machine interfacing
BOLD	Blood oxygenation level dependence
BSS	Blind source separation
Ca	Calcium
CANDECOMP	Canonical decomposition
CDR	Current distributed-source reconstruction
CF	Characteristic function
CJD	Creutzfeldt–Jakob disease
Cl	Chloride
CNS	Central nervous system
CSD	Current source density
CT	Computerized tomography

DC	Direct current
DCT	Discrete cosine transform
DLE	Digitally linked ears
DSM	*Diagnostic and Statistical Manual*
DTF	Directed transfer function
DWT	Discrete wavelet transform
ECD	Electric current dipole
ECG	Electrocardiogram/electrocardiography
ECoG	Electrocorticogram
ED	Error distance
EEG	Electroencephalogram/electroencephalography
EGARCH	Exponential GARCH
EGG	Electrogastrography
EKG	Electrocardiogram/electrocardiography
EM	Expectation maximization
EMG	Electromyogram/electromyography
EOG	Electrooculogram
EP	Evoked potential
EPSP	Excitatory postsynaptic potential
ERD	Event-related desynchronization
ERP	Event-related potential
ERS	Event-related synchronization
FA	Factor analysis
FEM	Finite element model
FFNN	Feedforward neural network
FHWA	First half-wave amplitude
FHWD	First half-wave duration
FHWS	First half-wave slope
fICA	Fast independent component analysis
FIR	Finite impulse response
fMRI	Functional magnetic resonance imaging
FOCUSS	Focal underdetermined system solver
FSP	Falsely detected source number percentage
GA	Genetic algorithm
GARCH	Generalized autoregressive conditional heteroskedasticity
GARCH-M	GARCH-in-mean
GFNN	Global false nearest neighbours
GJR-GARCH	Glosten, Jagannathan, and Runkle GARCH
HCI	Human–computer interfacing/interaction
HMM	Hidden Markov model
HOS	Higher-order statistics
IBE	International Bureau for Epilepsy
ICA	Independent component analysis
IIR	Infinite impulse response
ILAE	International League Against Epilepsy

IPSP	Inhibitory postsynaptic potential
IR	Impulse response
ISODATA	Iterative self-organizing data analysis technique algorithm
JADE	Joint approximate diagonalization of eigenmatrices
K	Potassium
KL	Kullback–Laibler
KLT	Karhunen–Loéve transform
KT	Kuhn–Tucker
LD	Linear discriminants
LDA	Linear discriminant analysis
LDA	Long-delta activity
LE	Lyapunov exponent
LEM	Local EEG model
LLE	Largest Lyapunov exponent
LMS	Least mean square
LORETA	Low-resolution electromagnetic tomography algorithm
LP	Lowpass
LRT	Low-resolution tomography
LS	Least squares
LWR	Levinson–Wiggins–Robinson
MA	Moving average
MAF	Multivariate ambiguity function
MAP	Maximum *a posteriori*
MDP	Moving dipole
MEG	Magnetoencephalogram
MI	Mutual information
MIL	Matrix inversion lemma
ML	Maximum likelihood
MLE	Maximum likelihood estimation
MLE	Maximum Lyapunov exponent
MLP	Multilayered perceptron
MMN	Mismatch negativity
MP	Matching pursuits
MRI	Magnetic resonance imaging
MS	Mean square
MS	Multiple sclerosis
MSE	Mean-squared error
MTLE	Mesial temporal lobe epilepsy
MUSIC	Multichannel signal classification
MVAR	Multivariate autoregressive
Na	Sodium
NLMS	Normalized least mean square
NMF	Nonnegative matrix factorization
NN	Neural network
NREM	Nonrapid eye movement