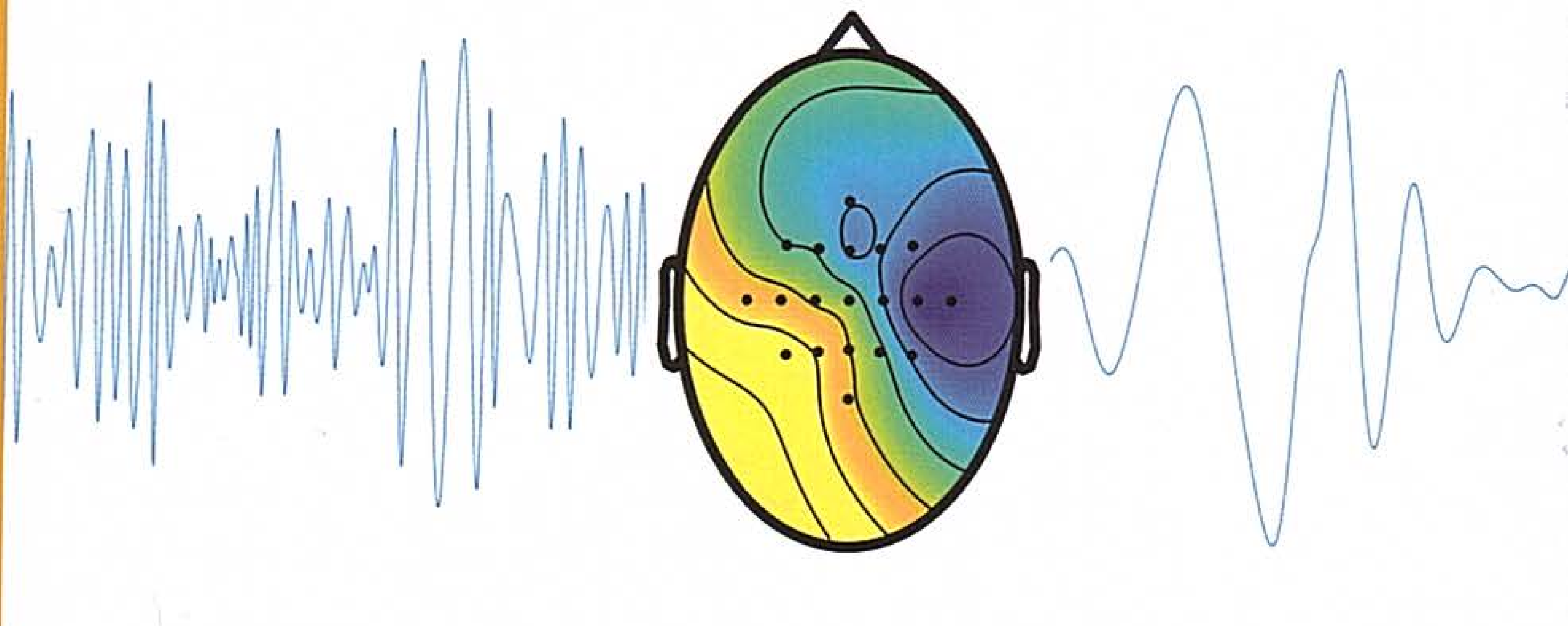
Biomedical Signal Analysis

RANGARAJ M. RANGAYYAN
SRIDHAR KRISHNAN

Third Edition



with website

IEEE Press Series in Biomedical Engineering
Metin Akay, Series Editor

IEEE Engineering in Medicine
and Biology Society, Sponsor

IEEE PRESS

WILEY

FOREWORD BY PROF. ALAN V. OPPENHEIM

I'm delighted to have this opportunity to express my thoughts about the Third Edition of Biomedical Signal Analysis and more broadly about the field of signal processing. When asked, I was totally unfamiliar with the previous editions of the book and had only a cursory familiarity with biomedical signals and issues related to that specific application of signal processing. My entire academic career as a researcher and teacher, spanning about seven decades, has been primarily focused on the theoretical aspects of signal processing and the applications to speech, radar, communications, and image analysis and processing. Being invited to write a foreword for this edition has been an opportunity for me to delve more deeply into how signal processing has been and can be used for the analysis and processing of biomedical signals and data. More broadly, it also offers me the opportunity to comment on the audience that I see this book as being best matched to and to also express some personal thoughts and comments about the field of signal processing.

Biomedical signal analysis, either formally or informally, has a long and rich history going back centuries and even millennia. Listening to acoustic signals from the heart and lungs and introducing and analyzing echoes from acoustic and higher frequency signals penetrating the body have long been well-established noninvasive diagnostic methodologies. And over many centuries, these techniques have been significantly enhanced by the invention of various transducer and sensor technologies, such as the stethoscope, X-ray and ultrasound imaging, and the MRI. With modern technology, an increasing number of highly sophisticated transducers and sensors are being developed and introduced to generate and capture biomedical signals and data for analysis on-line (that is, in real time) or off-line for screening and diagnostic purposes. As transducer, sensor, and signal processing algorithms advance, there are an increasing number of low-cost sophisticated devices for home and personal use. Overall, the field of biomedical signal analysis has become an increasingly important application area for utilizing sophisticated signal processing methods and tools and for the development of new signal processing methodologies with applications beyond this specific class of signals.

In the preface to the previous editions and this new edition, the authors indicate, as the intended audience, engineering students in their final year of undergraduate studies; specifically, that

> "Electrical Engineering students with a good background in Signals and Systems will be well prepared for the material in this book. A course on Digital Signal Processing or Digital Filters would form a useful link to the material in the present book, but a capable student without this background should be able to gain a basic understanding of the subject matter."

From my perspective, I see great value and potential hazards for some audiences. As the authors point out, for students and practitioners with a strong background in signal processing and who are just becoming involved with this application area, this book provides an excellent high-level introduction to a wide variety of biomedical signals as well as an overview of a wide variety of signal processing methodologies with rich examples of how these might be or are being applied to this class of signals. It does not nor does it claim to present these methodologies in any depth. It assumes that the reader either has the necessary background or is capable of acquiring it. Students with the background of a previous undergraduate course in signals and systems will likely be equipped to understand the signal processing terminology in the earlier chapters of this book. Signal processing concepts such as Wiener filtering, time–frequency analysis, and wavelets are more typically discussed in more advanced courses. Many of the signal processing concepts referred to in this book can easily appear simple and familiar on the surface, but their effective use ultimately depends on a relatively sophisticated understanding of the techniques, the underlying assumptions, and their limitations.

Many of the basic tools of signal processing are developed from a mathematical formulation of the objectives of the processing. While signal processing technology is firmly grounded in mathematical analysis, its effective use in practical environments is an art. An important component of the art of signal processing is in understanding the objectives, the assumptions in the development of the tools, and the tradeoffs involved. There now exist a variety of signal processing toolboxes that are more or less "plug and play," that is, relatively straightforward to apply to a data set. The art is in choosing which to use, how to set the parameters, and how to interpret the results. For example, filtering, as discussed in Chapter 3, is one of the fundamental sets of techniques in signal processing. The most typically used digital filter designs (Butterworth, Chebychev, elliptic IIR filters, data truncation and windowing, Parks–McClellan, and Savitzky–Golay FIR filters) are all "optimum" designs for filtering and data smoothing, but with different optimality criteria and different assumptions about the data and about the objectives of the processing. Each introduces different trade-offs between time-domain and frequency-domain characteristics. Consequently, in utilizing any filter design package, it is essential for the user to understand carefully the assumptions and trade-offs associated with the various filter designs. As I often like to comment:

> *"anything's optimum if you pick the error criterion correctly. And just because it's optimum doesn't mean it's good."*

Another basic set of tools in signal processing is directed at or based on characterizing the frequency content in signals, that is spectral analysis as discussed in Chapter 6 and illustrated in a number of other chapters. There are many available software packages for use in spectral analysis of biomedical signals, but here again, they are developed based on underlying assumptions and objectives. Some level of stationarity in the data is, of course, one of them, and trade-offs and assumptions about the length of the data record and the underlying spectral content is another. Here again, spectral analysis of data has a long history, with many of the standard procedures more or less optimum under different formulations of optimality. For example, there is a significant difference in how one should approach spectral analysis of a data set in attempting to identify a narrowband signal in a data set versus characterizing the spectral content in a broadband signal in the presence of noise.

For data that is nonstationary in the underlying assumptions, adaptive and time–frequency analysis methods are an important part of the signal processing toolset. Many of these are discussed or mentioned in the latter chapters of the book (for example, Chapters 7, 8, and 9), but again, the reader is cautioned to understand carefully the basis for and the underlying assumptions of these methods before applying them from a readily available toolbox to their particular data sets. In a purely theoretical sense, we can choose to characterize a signal in either the time domain or, through the Fourier transform, the frequency domain. While intuitively we can refer to a signal as having "time-varying frequency content," a precise description of what we mean by that is often elusive. Theoretically, you're either in the time domain or in the frequency domain, not wandering somewhere in between. While appropriately many biomedical signals are best characterized through some notion of "time-varying frequency content," considerable care is required in interpreting what is meant by that and which tools are appropriate in a given context.

In summary, I see this book as a wonderful resource for students and practitioners who have a relatively strong signal processing background and who are working or are beginning to work with biomedical signals. I would also emphasize the cautionary note that the effective use of signal processing techniques and toolboxes is an art, and having a solid understanding of these tools is essential for their effective use. Creatively and artfully applying the tools, and perhaps modifying them, require a good understanding of the theory and mathematics behind them.

ALAN V. OPPENHEIM, SC.D., FIEEE

Ford Professor of Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA
July, 2023