Preface

Bioelectrical signals have been recorded and analyzed for several decades but still continue to excite physicians and engineers. Novel signal processing techniques have helped uncover information which completely changed the way various diseases previously were diagnosed. In fact, it is today difficult to imagine a situation when diseases related to the heart, the brain, or the muscles are diagnosed without also including certain information derived from bioelectrical signals. Such information is essential to therapeutic devices in cardiac, neurological, and neuromuscular applications, and will in the future, when systematically fused with other types of biomedical signals, continue to improve the quality of life of many patients. Monitoring of home-based patients is becoming increasingly popular in health care, frequently involving bioelectrical signals which can be safely and comfortably recorded using noninvasive techniques.

The aim of this book is to present a comprehensive overview of techniques with particular relevance to the processing of bioelectrical signals. The presentation is problem-driven and deals with issues having received considerable attention from both a scientific viewpoint, i.e., in the form of publications and conference presentations, and a viewpoint of product development. Since biomedical signal processing has been largely synonymous with the processing of ECG, EEG, EMG, and evoked potentials, we have focused the presentation on issues related to these four types of bioelectrical signals. It is yet our conviction that the reader is fully capable of transferring the way of thinking developed herein for bioelectrical signals, as well as to transfer the developed methods, when later dealing with other types of biomedical signals.

Choosing a problem-driven presentation means, in this book, that different methods are described within the context of a certain bioelectrical signal. For example, power spectral analysis is described within the context of EEG signal processing though such analysis is certainly well-established in other biomedical applications as well. While some may feel that the realm of a method's usefulness is depreciated with this kind of presentation, we hope nonetheless that the power in connecting a particular type of signal to a particular method outweighs the disadvantages. On occasion, the problem-driven presentation also means the display of a smorgasbord of methods developed to solve a certain problem such as the cancellation of powerline interference. We hope that this way of dealing with a problem would serve the reader well by offering an idea of the diversity with which a problem can be solved. Not all methods considered in this textbook are directly applicable in clinical practice but may require one or several heuristic add-ons before their performance become satisfactory; the exact definition of such add-ons is rarely disclosed in the original publication of a method but needs to be developed by those interested in the method's pursuit.

With the display of different methods for solving a particular problem comes the natural wish of knowing which method offers the best performance. We have, however, abstained from making such comparisons due to the many pitfalls associated with choosing performance measure, data set, and so forth. We would instead like to challenge the reader to delve into this important aspect.

Biomedical signal processing has today reached certain maturity as an academic subject and is now supported by the availability of a handful of textbooks. Being an interdisciplinary subject by nature, biomedical signal processing has to be taught quite differently depending on the educational program. For students in biomedical engineering a course in physiology is part of the curriculum, whereas students in electrical engineering and computer science usually lack such a course. In order to maintain the interdisciplinary nature when teaching the latter group of students, we have included chapters or sections with brief, self-contained introductions to the underlying electrophysiology, recording techniques, and some important clinical applications. Without any prior knowledge of these aspects, a course in biomedical signal processing runs the risk of losing its very essence.

It is evident that a course on biomedical signal processing may embrace widely different contents—an observation which not only applies to the choice of biomedical signals but also to the choice of methodologies. Rather than yield to the temptation to include as much as possible, we have deliberately avoided to cover certain important techniques including pattern recognition, artificial neural networks, higher-order statistics, and nonlinear dynamics. Though important in biomedical applications, the fundamentals of these techniques are well-covered by a number of textbooks.

This book is intended for final year undergraduate students and graduate students in biomedical engineering, electrical engineering, and computer science. It is suitable for a one-quarter or one-semester course depending on the content covered and the amount of emphasis put on problem solving and project work. A necessary prerequisite is the fundamentals of digital signal processing as presented in textbooks such as [1, 2]. Since many recent methods used in biomedical applications are based on concepts from statistical modeling and signal processing, a basic course in probability theory and stochastic processes is another important prerequisite. It is also desirable that the reader has certain familiarity with linear algebra so that common matrix operations (summarized in Appendix A) can be performed. Readers who want to achieve a deeper understanding of statistical signal processing are referred to a number of highly recommended textbooks on this topic [3–5]. Adaptive filtering is a topic which is just briefly touched upon in this book; comprehensive coverage of such filters and their properties can be found in [6].

This book may also be used as a comprehensive reference for practicing engineers, physicians, researchers and, of course, anyone interested in finding out what information can be derived from bioelectrical signals. For practicing engineers, we have used selected parts of the book for a short course on biomedical signal processing (i.e., 2–3 days); in such cases, the main emphasis should be put on the significance of different methods rather than on mathematical details.

Contents Overview

Chapter 1 puts biomedical signal processing in context, and gives a brief description of bioelectricity and its manifestation on the body surface as signals. General aspects on signal acquisition and performance evaluation are briefly considered.

Chapter 2 provides the reader with the basics of the brain, serving as a background to the following chapter on EEG signal processing. Some common EEG patterns are described and their relationships to cerebral pathology are pointed out. An understanding of EEG signal characteristics, as well as the purposes for which the characteristics can be exploited, is essential information when assimilating the contents of Chapter 3. The main themes in Chapter 3 on EEG signal processing are related to artifact rejection and spectral analysis; two techniques of critical importance to EEG interpretation. Special attention is given to the multitude of spectral analysis techniques and a section on time–frequency analysis is included.

Chapter 4 provides a comprehensive overview of noise reduction techniques for use with event-related signals, here treated within the context of evoked potentials. Similar to EEG signals and spectral analysis, evoked potentials and signal averaging became "partners" at a very early stage in the history of biomedical signal processing, thus motivating the emphasis on this partnership. The overview of noise reduction techniques covers both ensemble averaging (and its spawn) and more advanced approaches where the signal is modeled and filtered using a basis function expansion; wavelets represent one such popular approach.

Chapter 5 deals with myoelectric activity and the related EMG signal recorded either by noninvasive or invasive techniques (and makes a minor departure from the general framework of dealing with signals recorded on the body surface). Of the many developed methods for EMG signal analysis, we cover some central ones related to muscle force and conduction velocity where signal modeling and statistical estimation techniques are involved.

Chapter 6 contains a background to the electrophysiology of the heart, describes the main characteristics of the ECG signal in terms of morphology and rhythm, and prepares the way for Chapters 7 and 8 by mentioning the most important ECG applications. Chapter 7 describes a suite of methods, essential to any system which performs ECG signal analysis, developed for the purpose of noise reduction, heartbeat detection and delineation, and data compression. Chapter 8 is completely devoted to the analysis of heart rate variability—an area of considerable clinical and technical interest in recent years—and describes techniques for representing and characterizing such variability in the time and frequency domain.

We have included an extensive, but not exhaustive, number of references which give the interested reader rich possibilities to further explore the original presentations of the methods. References are almost exclusively made to journal publications since these are easily retrieved from libraries. As a result, the very first publication of a method, often appearing in a conference proceeding, is not acknowledged for which we apologize.

A collection of problems has been developed in order to illustrate the presented methods and their applications. While some problems are straightforward to solve, others require considerable effort and background knowledge and are intended as "appetizers" for students interested in pursuing research in biomedical signal processing. An accompanying manual with detailed solutions to all problems is available at the publisher's web site

www.books.elsevier.com/0124375529

to instructors who adopt the book.

Any course on biomedical signal processing must include one or several projects which give the student an opportunity to process signals and to learn the pros and cons of a method. We have developed a companion web site where several project descriptions are listed and signals available for download; its location is

www.biosignal.lth.se

An important goal with this web site is to allow the inclusion of new projects so that projects can be submitted by anyone interested in teaching the contents of this book (submission instructions are available at the web site).

Those interested in using this book for a one-quarter course may want to omit the sections on time–frequency analysis (Section 3.6), basis functions and related adaptive analysis (Sections 4.5 and 4.6), wavelets (Section 4.7), and certain parts of Chapter 8 dealing with heart rate variability; the mathematical level is relatively advanced in all these parts. A shorter course may to a lesser extent deal with problem solving, however, we strongly encourage the inclusion of at least one project since it provides the student with experiences essential to the understanding of biomedical signal processing.

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Pablo Laguna

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