Spectral Analysis of Signals by Petre Stoica and Randolph Moses, Pearson Prentice-Hall, 2005, ISBN: 0-13-113956-8, 480 pages, hardbound. *Reviewed by Hongbin Li, Stevens Institute of Technology, Hoboken, NJ, Hongbin.Li@stevens.edu*

Spectral analysis is an important topic that is relevant to a diverse set of applications. Founded in basic Fourier analysis, spectral analysis has evolved into a set of modern techniques used for wireless communications, speech coding, medical imaging, remote sensing, seismology, astronomy, and other applications. Because of its fundamental importance to many areas of engineering, spectral analysis is often taught in one or two lectures in graduate signal processing classes. Yet, in fact, an entire semester could be devoted to a complete and systematic treatment of the subject.

Stoica and Moses' recent book, *Spectral Analysis of Signals*, is a revised and expanded version of *Introduction to Spectral Analysis* by the same authors, a popular text and reference on the subject since its publication in 1997. While retaining several unique and favorable features of the earlier version, the authors have significantly expanded the content by including recent developments in the field, thereby making it more than an introductory text. They have catered to a broader audience, including senior undergraduate and graduate students, as well as engineers and other professionals. The material can easily fit in a one-semester spectral analysis course. Depending on the background and level of the students, the course may include more advanced and challenging topics selected from the complements and appendices, which are organized such that individual topics are self-contained.

The book consists of six chapters and four appendices. The main text of each chapter discusses the principles and fundamentals, while the complements included at the end of each chapter examine more advanced topics. Much of the background material needed for the book, such as linear algebra, Cramér-Rao bound analysis, and model order selection, is provided in the appendices. Spectral estimation techniques are broadly classified either as nonparametric (Chapters 2 and 5) and parametric (Chapters 3 and 4) methods; or temporal (Chapters 2–5) and spatial (Chapter 6) methods.

The book begins with a brief introduction to spectral analysis in Chapter 1. The authors then progress to discuss Fourier-based, nonparametric methods—including the periodogram, correlogram, and several enhanced versions with reduced variance—in Chapter 2. Parametric methods for rational spectra are detailed in Chapter 3. For autoregressive (AR) signals, the Yule-Walker (YW) and least-squares (LS) methods, along with efficient recursive solutions to the YW equations, are discussed. For autoregressive moving-average signals, a modified YW method and a two-stage LS method are described; the latter can also be used to estimate moving-average spectra. Parametric methods for line spectra based on a sinusoidal model are featured in Chapter 4. The main problem discussed is how to estimate the sinusoidal frequencies from noisy observations. A number of frequency estimators are presented, including the nonlinear LS estimator, which has good statistical performance but high complexity. This observation motivates the exploration of several computationally more attractive subspace estimators. The authors point out that the various subspace methods have similar computational complexity and statistical accuracy, and that the choice is largely "a matter of taste." The nonparametric spectral estimation problem is revisited in Chapter 5 through a filter-bank approach, which has received considerable research interest in recent years. The filter-bank approach subsumes a large class of nonparametric methods, including the classical Fourier-based estimators (which are data-independent) and the more elaborate data-adaptive Capon method. Several new spectral estimators, such as the APES estimator (discussed in one of the book's complement sections), were also obtained within this framework. In this reviewer's opinion, Chapter 5 is the most updated and systematic textbook treatment of the filter-bank approach available today. Finally, the closely related beamforming and direction-of-arrival estimation problems are considered in Chapter 6. A number of methods, which have been introduced in earlier chapters for temporal spectral estimation, are extended to solve the spatial spectral estimation problem.

Overall, this book has many distinctive features that make it attractive both as a reference and as a textbook. The main text is concise without sacrificing rigor and readability. The material is presented in a coherent and integrated fashion. Since a beginner in the field can easily be overwhelmed by myriads of confusing and seemingly isolated spectral estimators, the authors have made significant effort to discuss the relationships between different methods and, by

doing so, reveal connections that are often lost. Furthermore, in various locations in the text, the authors provide different mathematical approaches to arrive at the same result. The overall result should help the reader develop a bigger picture of the topic and obtain a deeper understanding of the principles behind various methods. Notable examples of such efforts include the equivalence of different nonparametric methods established in Chapter 2, filter-bank interpretation of the Fourier-based methods, and the relationships between the Capon and AR spectral estimates in Chapter 5.

Moreover, the book is timely. Published in 2005 and authored by pioneers who are at the forefront of spectral analysis research, the book covers a number of methods that appeared only within the last few years, such as the amplitude and phase estimation from gapped data and the robust Capon beamformer, to name just a few. The bibliography has been considerably expanded to reflect recent developments.

The book features an attractive integration of MATLAB code with the text's material. MATLAB is arguably the most popular simulation tool for signal processing (SP) and is now widely used in many schools to teach SP-related courses. The authors have developed a sophisticated tool (available from the authors' Web site) consisting of a suite of MATLAB functions for spectral analysis and data generation. The book contains limited numerical examples and graphical illustrations depicting the performance of various methods. However, such results can easily be obtained by using the authors' MATLAB tool, and the readers are encouraged to "play" with the tool in computer-based exercises included at the end of each chapter.

Finally, pedagogical needs have been carefully considered as well. The book contains an appropriate amount of traditional paper-and-pencil problems as well as computer-based exercises of varying levels of difficulty. The authors also provide answers to selected problems in an appendix. The computer-based exercises are designed to verify analytical results developed in the text and provide numerical evaluation or comparison of different methods. Instructors will be happy to know that an extensive solutions manual is available from the publisher and that detailed slides are available for download from the authors' Web site to facilitate more rapid course development.

Compared to other available references in spectral analysis—such as Steven Kay's *Modern Spectral Estimation: Theory and Application*—which often approach spectral estimation from a lengthy mathematical viewpoint, this book streamlines the discussions to make the material easily accessible to a broader audience. Overall, Stoica and Moses have done a remarkable job in avoiding unnecessary and drawn out mathematical derivations. One notable example is the Levinson-Durbin algorithm, for which the authors use only a few steps to complete the development, whereas a standard derivation based on linear prediction provided in other books typically requires many pages. Mathematical conciseness is achieved by skillful and oftentimes insightful use of linear algebra and matrix analysis, and most of these results are provided in Appendix A. In my opinion, Appendix A has reference value by itself, as the results included there are frequently used to solve other signal processing problems.

In summary, the book is well written and designed for a broad range of readers—students and instructors, novices and pros. Like its 1997 predecessor, this reviewer expects that the book will continue to be a popular text in spectral analysis and a valuable reference to anyone interested in conducting research in this field. SP

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This index covers all technical items — papers, correspondence, reviews, etc. — that appeared in this periodical during 2006, and items from previous years that were commented upon or corrected in 2006. Departments and other items may also be covered if they have been judged to have archival value.

The Author Index contains the primary entry for each item, listed under the first author's name. The primary entry includes the coauthors' names, the title of the paper or other item, and its location, specified by the publication abbreviation, year, month, and inclusive pagination. The Subject Index contains entries describing the item under all appropriate subject headings, plus the first author's name, the publication abbreviation, month, and year, and inclusive pages. Subject cross-references are included to assist in finding items of interest. Note that the item title is found only under the primary entry in the Author Index.

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