Classical and Modern Direction-of-Arrival Estimation

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Contents

Preface

The need for direction-of-arrival (DOA) estimation arises in many engineering applications including wireless communications, radar, radio astronomy, sonar, navigation, tracking of various objects, and rescue and other emergency assistance devices. In its modern version, DOA estimation is usually studied as part of the more general field of array processing. Much of the work in this field, especially in earlier days, focused on radio direction finding—that is, estimating the direction of electromagnetic waves impinging on one or more antennas.

The problem of acoustic direction estimation was also studied extensively, mostly in the context of sonar. In fact much of the development of what is now called "modern DOA estimation" was done for sonar applications where the relatively small bandwidth of the signals to be processed made the computational requirements of advanced algorithms feasible with the technology that existed then. As processing power kept increasing, it became possible to apply advanced techniques to the more demanding wider bandwidth communications and radar signals.

While DOA estimation is now a mature field with a solid theoretical basis and a large number of practical applications, it is still an evolving and quite active field of research. This book attempts to provide a snapshot of the most recent work on this ubiquitous problem and, at the same time, to provide a brief review of the more classical work on direction finding.

The book contains ten chapters. Chapter 1 by Friedlander lays out the fundamentals of the DOA problem. Starting with a discussion of how it all originated, it blends both classical and modern techniques. Chapter 2 by Demmel is a good reference for practicing engineers. It presents the techniques currently used in commercial direction-finding (DF) systems. Chapter 3 by Viberg, Lanne, and Lundgren presents a critical topic for sensor arrays, namely calibration. Different techniques for calibration are presented and numerically compared in this chapter. Chapter 4 by Tuncer, Yasar, and Friedlander discusses narrowband and wideband processing for DOA estimation. The advantages of array interpolation and processing gain achieved by wideband processing are outlined. Chapter 5 by Rübsamen and Gershman presents techniques for search-free DOA estimation for different arrays. Such techniques allow one to use fast algorithms for some unconventional array structures.

Chapter 6 by Amin and Zhang introduces a new dimension to the DOA problem—namely, spatial time-frequency distributions. Direction-of-arrival estimation can be improved as a result of signal-to-noise ratio (SNR)

enhancement and source discrimination in the time-frequency domain. Chapter 7 by Abramovich, Johnson, and Mestre discusses an interesting problem in the threshold region. The expected likelihood approach is used as a mechanism to assess the quality of estimates for the low sample case. Chapter 8 by Chevalier, Ferréol, and Albera presents the advantages of higher-order statistics compared to second-order statistics for direction of arrival. It has been shown that a virtual increase of the array aperture by the introduction of virtual sensors can be used to improve resolution and modeling errors. Chapter 9 by Chen and Yao discusses the localization problem in sensor networks. Both maximum likelihood formulation and performance bounds are presented for source localization. Chapter 10 by Amar and Weiss advocates direct position determination for source localization. It has been shown that superior results can be obtained at low SNR even when there are modeling errors.

Acknowledgments

We wish to thank all the authors for their high-quality contributions. This book is a reflection of what is believed to be the renewed interest of people in array signal processing and, more specifically, DOA estimation. It is hoped that this book will be a catalyst for a much wider interest and further collaboration.

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Yuri I. Abramovich (an IEEE Fellow) received the Dipl.Eng. (Hons.) degree in radio electronics in 1967 and the Cand.Sci. degree (Ph.D. equivalent) in theoretical radio techniques in 1971, both from the Odessa Polytechnic University, Odessa (Ukraine), USSR. In 1981, he received the D.Sc. degree in radar and navigation from the Leningrad Institute for Avionics, Leningrad (Russia), USSR. From 1968 to 1994, he was with the Odessa State Polytechnic University as a research fellow, professor, and ultimately as Vice-Chancellor of Science and Research. From 1994 to 2006, he was at the Cooperative Research Centre for Sensor Signal and Information Processing (CSSIP), Adelaide, Australia. Since 2000, he has been with the Australian Defence Science and Technology Organisation (DSTO) in Adelaide as Principal Research Scientist, seconded to CSSIP until its closure. His research interests are in signal processing (particularly spatio-temporal adaptive processing, beamforming, signal detection and estimation), its application to radar (particularly over-the-horizon radar), electronic warfare, and communication. He is currently an Associate Editor of *IEEE Transactions on Aerospace and Electronic Systems* and previously served as Associate Editor of *IEEE Transactions on Signal Processing* from 2002 to 2005.

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Dr. Chevalier's present research interests are in array processing techniques, either blind or informed, second-order or higher-order, spatial- or spatio-temporal, time-invariant or time-varying especially for cyclostationary signals; linear or nonlinear and particularly widely linear for noncircular signals for applications such as TDMA, CDMA, and MIMO radiocommunications networks; satellite telecommunications, spectrum monitoring, and passive listening in HVUHF band. He was a member of the THOMSON-CSF Technical and Scientifical Council between 1995 and 1998. He coreceived the 2003 "Science and Defense" Award from the French Ministry of Defence for its work as a whole about array processing for military radiocommunications. He is author or coauthor of about 25 patents and 100 papers (journal, conferences, and chapters of books). Dr. Chevalier is presently an emeritus member of the Societé des Electriciens et des Electroniciens (SEE).

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