SpringerBriefs in Electrical and Computer Engineering

More information about this series at http://www.springer.com/series/10059

Jacob Benesty · Jingdong Chen
Chao Pan

Fundamentals of Differential Beamforming

Springer

Jacob Benesty
INRS-EMT, University of Quebec
Montreal, QC
Canada

Chao Pan
Northwestern Polytechnical University
Xi’an
China

Jingdong Chen
Northwestern Polytechnical University
Xi’an
China

ISSN 2191-8112 ISSN 2191-8120 (electronic)
SpringerBriefs in Electrical and Computer Engineering
ISBN 978-981-10-1045-3 ISBN 978-981-10-1046-0 (eBook)
DOI 10.1007/978-981-10-1046-0

Library of Congress Control Number: 2016937935

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Science+Business Media Singapore Pte Ltd.

Contents

Abstract

Microphone arrays can be used in a broad range of applications from telecommunications, teleconferencing, and smart home systems to intelligent human–machine interfaces to deal with many important acoustic problems such as noise reduction, source separation, dereverberation, source localization/tracking, robust hands-free speech recognition, to name a few. Significant efforts have been devoted to the design of such arrays and the associated processing algorithms since the 1970s. In the literature, microphone arrays are generally classified into two major categories: additive and differential. The former refers to arrays with large sensor spacing whose outputs are responsive to the acoustic pressure field; whereas the latter refers to arrays with small sensor spacing whose outputs are responsive to the differential acoustic pressure field of different orders. While both types of arrays have their own pros and cons, when applied to solving a real problem, differential microphone arrays (DMAs) are more appropriate for high-fidelity signal enhancement applications as they have the potential to form frequency-invariant directivity patterns and attain large directional gains with small and compact apertures.

This book is intended to provide a systematic study of the fundamental theory and the methods of beamforming with DMAs, or differential beamforming in short. From a physical perspective, a DMA of some order is defined as an array that measures the differential acoustic pressure field of that order; such an array has a beampattern in the form of a polynomial whose degree is equal to the DMA order. Therefore, the fundamental and core problem of differential beamforming boils down to the design of beampatterns with orthogonal polynomials. But constraints have to be considered so that the resulting beamformer does not seriously amplify sensors' self-noise and mismatches among sensors. In this work, we first present a brief overview of differential beamforming and some popularly used DMA beampatterns such as dipole, cardioid, hypercardioid, and supercardioid. Then, some background knowledge on orthogonal functions and orthogonal polynomials is provided, which forms the basis of differential beamforming. Several performance criteria are subsequently revisited, which can be used to evaluate the performance of the derived differential beamformers. Next, differential beamforming is cast into a framework of optimization and linear system solving and it is shown how different beampatterns can be designed with this optimization framework. After that, several approaches are presented to the design of differential beamformers with the maximum DMA order, with the control of the white noise gain, and with the control of both the frequency invariance of the beampattern and the white noise gain. Finally, a joint optimization method is explained, which can be used to derive differential beamformers that have almost frequency-invariant beampatterns and meanwhile are robust to sensors' self-noise.