Battlefield Acoustics

Thyagaraju Damarla

Battlefield Acoustics

Springer

Thyagaraju Damarla
U.S. Army Research Laboratory
Laurel, MD
USA

ISBN 978-3-319-16035-1 ISBN 978-3-319-16036-8 (eBook)
DOI 10.1007/978-3-319-16036-8

Library of Congress Control Number: 2015935214

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

To my mother, Ravamma Damarla, who inculcated the importance of education in me at an early age and my father, Ramakantarao Damarla, whose image with a book in hand is etched in my mind forever.

Preface

Situational awareness in the battlefield is an age-old quest. The advent of modern sensors and advances in digital signal processing is making the art of inference from sensor data far more feasible. Acoustic sensors are the ears in the field. One should strive to understand the situation based on what is heard in the area. Moreover, acoustic sensors are omnidirectional and consume less power, so they last a longer once deployed, unlike other sensors, which require frequent change of batteries. As a result, there is a lot of interest in acoustics and its signal processing.

When I first started working in the Acoustics Branch, there were no books that dealt with battlefield acoustics. For the majority of cases, one is forced to look for articles in various journals. Although this contributed to deeper learning and understanding of the subject, a book on the battlefield acoustics would have been a good starting point to help in focusing the search. Situational awareness for intelligence, surveillance, and reconnaissance (ISR) requires detection, classification, and tracking of targets, which could be ground or airborne vehicles, people, hostile gunfire, etc. While performing acoustic signal processing, one should also understand the dynamics of acoustic waves. For example, just as with light, acoustic waves undergo reflection and refraction, which, in turn, have a dramatic effect on the acoustic signals. Thus, while processing acoustic signals, the effects of reflection and refraction should be taken into account.

The organization of the book is as follows. We begin with an introduction to various types of microphones in Chap. 1. The next three chapters present some of the concepts in probability, detection, and estimation theory that are essential for acoustic signal processing. Those with some knowledge of these theories can skim or skip Chaps. 2 through 4.

Chapter 5 presents some concepts in physical acoustics, including the properties of reflection and refraction of acoustic waves. The concept of ground impedance, which plays a significant role in the ground reflection of acoustic signals, is also explored.

Chapter 6 focuses on the theory of microphone arrays. Here, several configurations of microphones, namely linear, circular, and grids of microphones are considered. The beam widths of such arrays are also estimated and the concept of

spatial aliasing is presented. This theory is fundamental in constructing an array for estimating the direction of arrival (DOA) of sound sources depending on the mission. DOA estimation of signals to determine from where they are emanating is vital for finding their location and tracking them—a fundamental aspect of situational awareness. Further, DOA estimation depends on the type of waves that the source is emitting. For example, vehicles emit continuous signals, whereas gunfire, mortar launchings, and detonations emit transient sounds, that is, short bursts of sound.

Chapter 7 details the estimation of DOA from continuous sound sources, covering several methods, namely adaptive beamforming and eigenvector-based techniques. The multiple signal classification (MUSIC) and minimum variance distortionless response (MVDR) techniques are discussed at length. To assist in experimentation, the corresponding MATLAB code is also presented as a jumping off point on the subject. The chapter explains how in order to track a target, several arrays must be deployed so that the estimated DOAs at each array can be used to triangulate to find the location of the target.

Chapter 8 deals with a very important related topic: the fact that often such DOAs are noisy, which means the estimates of the target locations are also noisy at best. To address this issue, the chapter outlines the theoretical concepts of various filters that can be used. Specifically, sequences of target estimations are used to track targets using Kalman, extended Kalman, unscented Kalman, and particle filters. Again, to assist in experimentation the MATLAB code for each filter is also presented.

Chapter 9 considers the nature of transient sound signals that occur mainly due to gunfire or mortars, focusing on the specific problem of determining a sniper's location. Given that supersonic guns emit both shockwave and muzzle blast signals, the speed of a supersonic bullet can be determined by the N-wave due to shockwave. The relevant theory is presented with this chapter. Also, localization of gunfire can be determined by finding the time difference of arrival of the muzzle blast signals at distributed microphones; this theory is also presented in the chapter.

Chapter 10 covers several commonly and most widely used classifiers used to classify signals from various targets, civilian and military vehicles, people, etc. The chapter presents the principles of some of the most popular classifiers, namely multivariate Gaussian classifier, Gaussian mixture model, support vector machines, and neural networks.

Of course, situational awareness requires the knowledge and identity of the targets, and to classify/identify targets, one needs to extract target features that represent the physics-based phenomenology. Chapter 11 presents some of these features and their extraction for vehicles and people. This chapter also details some of the high fidelity features generated by ultrasonic signals to distinguish people and animals.

Quite often, multiple multimodal sensors are used to detect, identify, and track targets in order to improve the detection statistics. The theory of fusion of multiple detections is considered in Chap. 12.

It is my intent that this book will provide the basics of battlefield acoustics and the issues involved, and in so doing, pave the way for engineering solutions. I hope this book will be useful to the practicing engineering students who aspire to be knowledgeable on the subject of battlefield acoustics.

Laurel, March 2015 Thyagaraju Damarla

Acknowledgments

I would like to take this opportunity to thank the U.S. Research Laboratory for giving me the opportunity and resources to explore and understand, and the freedom to work on all aspects of battlefield acoustics for situational awareness. In particular, I would like to thank Mr. Nassy Srour and Dr. Tien Pham for their unwavering support and their confidence in me. I would also like to acknowledge the support provided me by the Signal and Image Processing Division.

I have a lot to be thankful for. I thank the Chinthakrindi Kanakayya Higher Secondary School, Mangalagiri; the Indian Institute of Technology, Kharagpur; and Boston University, for providing me free education and laying the foundation for my life in the field of beautiful science and engineering, and sparing me the grunt work of routine life. I thank all the teachers who touched my life with a magic wand and made me see the brighter future in education. I particularly thank Prof. Mark Karpovsky, Boston University, who was instrumental in my coming to the United States to pursue higher education.

I cannot thank enough Ms. Carol Johnson for taking on the burden of editing the whole book within a short time and doing a wonderful job. Because of her dedication and hard work, the book is in a decent form and easy to read.

I would also like to thank my brother Mr. Umamaheswara Rao Damarla who inculcated the discipline in me to read at an early age.

Finally, I thank my wife Mrs. Komala Bai Damarla profoundly for her patience and understanding all these years while I was writing the book. Her friendship, comfort, and persuasion were instrumental in writing this book.

Contents