Chapter 14
Bearing-Only Target Motion Analysis

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ABSTRACT

The main goal of the bearing-only target motion analysis (BOTMA) is to determine the target's kinematic parameters such as position, course, and speed by only using the bearings reported by an onboard passive sensor (e.g., a sonar or an ESM [electronic support measures] device). This chapter provides a brief description of the BOTMA problem. Next, it discusses the implementation of the Kalman filtering technique to solve the problem. The authors then discuss the variations of the Kalman filtering (i.e., the extended and unscented Kalman filters). They also propose a genetic algorithm metaheuristic that incorporates a novel search space narrowing technique to solve the BOTMA problem and present numerical results for different noise conditions. They finally highlight the future research directions for modeling and solving the BOTMA problem.

INTRODUCTION

In a naval operation, the detection, classification, range, and localization of a hostile target play a key role while making a decision of an engagement. Platforms executing surface and subsurface warfares generally rely on their active and passive sensors as their primary sources of information. When high emission control policy is applied and the stealthiness is necessary, passive sensors constitute the only source of data. In such cases, the target-tracking algorithms implemented in the Combat Information Center (CIC)'s of a naval vessel rely on the data provided by passive sensors and those algorithms are known as Target Motion Analysis (TMA).

Although TMA is generally used in anti-submarine warfare with passive sonars as the source of data, it is also used for any type of passive sensor, e.g. ESM (Electronic Support Measures) systems, which can provide bearing data. In an anti-submarine warfare, the sonar is the primary information source and

DOI: 10.4018/978-1-5225-5513-1.ch014

it provides bearing information along with the frequency of the sound signals. In case of Electronic Warfare, ESM Systems are the primary passive source and these systems usually provide bearing, frequency, PRI (Pulse Repetition Interval), PRF (Pulse Repetition Frequency), PW (Pulse Width) and antenna scan period information of the target. There are several different implementations of TMA algorithms, which take into account not only the bearing information but also the frequency, range rate or other available information in hand. In this chapter, we restrict our scope to the bearing only case, i.e. Bearing Only Target Motion Analysis (BOTMA), and do not discuss other types of implementations.

Direction finding algorithms used in passive systems such as sonar and ESM systems are error-prone because of the noise present in the propagation channel of the sound and electromagnetic waves. The additive receiver noise on the receiver front end may also generate erroneous bearing information. Moreover, due to the multipath effect, signals bouncing and arriving at the receiver front end from different paths may degrade the signal quality, which makes the direction finding process more complicated.

TMA algorithm provides the means of predicting the target's next position given the previous bearing measurements. In this sense, it can be defined as a tracking method as well as a target trajectory extractor. While working on a general TMA problem, one needs to make two important assumptions. First, it is assumed that target moves with a constant speed in a linear direction without changing its course in Cartesian coordinates (x-y plane). Second, is that the vessel collecting measurements needs to maneuver and change its course at least once in order to make the target observable. Therefore observability plays a key role in the success of TMA algorithm and will be discussed thoroughly in this chapter.

The well-known methods found in the literature usually use iterative methods such as the reputable Extended Kalman Filtering (EKF) to solve the target-tracking problem. There are two possible ways of processing data collected from the passive sensor. Batch processing is the offline processing of the noisy bearing measurements collected for a period of time. That is to say, data cannot be processed in real-time. On the other hand, iterative methods (e.g. EKF) are more suitable and give an opportunity to implement real-time TMA (Farina, 1999).

In addition to iterative methods, there are several papers in the literature solving the target-tracking problem by the use of evolutionary algorithms (Ince, Sezen, Saridogan, & Ince, 2009; Sonmez, Hocaoglu, & Genc, 2017) and they usually consider the batch processing case. The evolutionary algorithm used for TMA uses a set of noisy bearing measurements, simulates the target's movement with different speed, course and location parameters, calculates the bearings based on targets simulation parameters and own-ship parameters and tries to minimize the difference between bearings acquired from the passive sensor and the simulated bearings. As the difference decreases, the algorithm converges to the global minima and outputs a not optimal but a good enough solution. Since our objective is to minimize the difference, the problem becomes an optimization problem. When the maximum sensor detection ranges, different course, and speed combinations are taken into consideration, the solution space for TMA problem becomes very large and finding an optimal solution turns out to be a challenging task.

In this book chapter, target-tracking problem and Target Motion Analysis algorithms used in the literature will be examined in a detailed way. In the following subsections, observability, target-tracking algorithms such as the Extended Kalman Filtering and other iterative methods will be discussed. Following that the implementation of evolutionary algorithms on TMA problem will be considered. An implementation of the Genetic Algorithm (GA) on the Target Motion Analysis (TMA) problem will be given and a brief discussion of the results will be provided.

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