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Multisensor Detection in Randomly Arriving Impulse Interference using the Hough Transform

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1. Introduction

In this chapter, several advanced detection algorithms for Track-Before-Detect (TBD) procedures using the Hough Transform (HT) are proposed and studied. The detection algorithms are based on the scheme described in (Carlson et al., 1994) to use the Hough transform for simultaneous target detection and trajectory estimation. The concept described in (Carlson et al., 1994) accepts that a target moves within a single azimuth resolution cell, and the distance to the target is estimated for several last scans forming the (*r-t*) data space. The Hough transform maps all points from the (*r-t*) space into the Hough space of patterns. The association with a particular pattern is done by thresholding the Hough parameter space with a predetermined threshold. In order to enhance the target detectability in conditions of Randomly Arriving Impulse Interference (RAII), a CFAR processor is proposed to be used for signal detection in the (*r-t*) space instead of the detector with a fixed threshold as it is suggested in (Carlson et al., 1994). The results obtained show that such a Hough detector works successfully in a noise environment. In real-time and realistic applications, however, when the two target parameters (range and azimuth) vary in time, the usage of the Polar Hough transform (PHT) is more suitable for radar applications because the input parameters for the PHT are the output parameters of a search radar system. Such a Polar Hough detector combined with a CFAR processor is proposed for operation in RAII conditions. The results obtained by simulation illustrate the high effectiveness of this detector when operating in strong RAII situations. Finally, the TBD-PHT approach is applied to the design of a multi-channel Polar Hough detector for multi-sensor target detection and trajectory estimation in conditions of RAII. Three different structures of a nonsynchronous multi-sensor Polar Hough detector, decentralized with track association (DTA), decentralized with plot association (DPA) and centralized with signal

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association (CSA), are considered and analyzed. The detection probabilities of the three multi-sensor Hough detectors are evaluated using the Monte Carlo approach. The results obtained show that the detection probability of the centralized detector is higher than that of the decentralized detector. The DPA Hough detector is close to the potential of the most effective multi-sensor CSA Hough detector. The target measurement errors in the (*r-t*) space mitigate the operational efficiency of multi-sensor Hough detectors. The needed operational efficiency requires the appropriate sampling of the Hough parameter space.

In recent years, the mathematical methods for extraction of useful data about the behavior of observed targets by mathematical transformation of the received signals have been widely used for design of a set of highly effective algorithms for processing of radar information. As a result, the more precise estimates of moving target parameters can be obtained in very dynamic radar situations. Actually, the target trajectories are estimated based on several radar plots. In the process of trajectory estimation, it is very important to use all current information for the detected target - amplitude and spectrum of the signals reflected from targets, target geometric dimensions, coordinates etc. According to the classical method, a target trajectory is estimated by determining of an existing kinematical dependence between few measurements of target coordinates. An optimization problem is solved where the optimization criterion is minimization of the distance between the two target coordinates, expected and measured. As a rule, different modifications of both methods, Kalman filter and Bayesian estimation, are used in these algorithms. However, the real-time implementation of these algorithms demand serious computational resources because the number of optimization problems, solved in the process of trajectory estimation, increases exponentially with the number of trajectories and the measurement density in the surveillance area. Recently, another modern approach is often used for trajectory estimation.

In recent years the two mathematical transforms, Hough and Radon, become increasing attention. The use of these transforms makes it possible to map two-dimensional images containing straight lines into the space of possible straight line parameters, where each straight line in an image corresponds to the peak in the parameter space, which has coordinates equal to the respective straight line parameters. For that reason, these mathematical transformations are very attractive for applications related to detection of straight lines in images. Such areas of applications are, for example, image processing, computer vision, seismic studies and etc. The idea to use the standard Hough transform (HT) for joint target detection and trajectory estimation on the background of white Gaussian noise was firstly introduced in (Carlson et al., 1994). According to this concept a target is assumed to move within a single azimuth resolution cell, and the target range is estimated in each scan. The data stored for several last scans forms the matrix hereinafter called as the (*r-t*)-data space. The HT maps all points from the (r-t) space where the target is detected into the Hough space of straight line parameters. The association with a particular straight line is done by estimating the quantity of information extracted from the signals received from the target with coordinates associated with this line.

In order to enhance target detectability in RAII conditions, a CFAR processor can be used for signal detection in the (*r-t*) space instead of a detector with a fixed threshold proposed in (Carlson et al., 1994). It is well known that different CFAR processors can be applied to signal detection in a complex noise environment (Finn & Johnson, 1968; Rohling, 1983; Gandhi & Kassam, 1988; Goldman, 1990; Himonas, 1994). The adaptive CFAR processors for signal detection in conditions of RAII are studied in (Kabakchiev & Behar, 1996, Behar et al., 2000, Garvanov et al., 2003; Garvanov, 2003). In this chapter, it is assumed that the noise amplitude is a Rayleigh distributed random variable and therefore the noise power is an exponentially distributed variable. Different Hough detectors that employ CFAR processors such as *Cell Averaging* (CA), *Excision* (EXC), *Binary Integration* (BI), *Excision with Binary Integration* (EXC BI), *Adaptive Post detection Integration* (API), *K-stage Detector*, *Order Statistic* (OS) for signal detection in the (*r-t*) space are studied and compared in (Behar et al., 1997; Behar & Kabakchiev, 1998; Kabakchiev et al., 2005; Doukovska, 2005; Doukovska & Kabakchiev, 2006; Garvanov et al., 2006; Garvanov et al., 2007; Doukovska, 2007; Doukovska et al., 2008). The structure of these Hough detectors includes the following operations - CFAR signal detection in the area of observation and the HT of the target range measurements from the observation area into the Hough parameter space, binary integration of data in the parameter space and, finally, linear trajectory estimation. All these CFAR Hough detectors have been studied in cases when a target moves in the same azimuth direction at a constant velocity. The results obtained in (Kabakchiev, Garvanov, Kyovtorov et al., 2005; Kabakchiev & Kyovtorov et al., 2005; Behar et al., 2007; Kyovtorov, 2007) show that different CFAR processors work successfully in combination with a Hough detector in conditions of RAII, and allow to evaluate the parameters of the targets.

In real radar applications, however, when the two target parameters, range and azimuth, vary in time, the PHT can be successfully used because in that case the input parameters of the PHT are two polar coordinates of a target – range and azimuth. Such advanced structures of the TBD using the PHT (TBD-PHT) have been developed and studied in (Garvanov et al., 2006; Garvanov et al., 2007). The PHT is analogous to the standard HT and performs all the data collected for several previous scans into a single large multi-dimensional polar data map. The general structure of an adaptive Polar Hough detector with binary integration is similar to that of a standard Hough detector. The only difference between them is that the PHT uses (*range-azimuth-time*) space while the standard HT employs (*r-t*) space. The detection probability of a Polar Hough detector is calculated by Brunner's method as for a standard Hough detector. The use of the PHT instead of the standard HT allows detecting target trajectories in real situations when targets move at variable speeds along arbitrary linear trajectories.

The TBD approach that applies the HT to multi-sensor detection in conditions of intensive RAII is proposed in (Garvanov, 2007; Kabakchiev, 2007; Kabakchiev, 2008; Garvanov, 2008, Garvanov et al., 2008). As usual, the fusion center of a decentralized system applies binary integration of the data received from each sensor. In such a system, at the first stage, radars produce local decisions by the TBD-PHT processing and at the second stage - all the local decisions are transferred from radars into the fusion node where coordinates and time are associated in the Global Observation Space (GOS). The centralized system, however, firstly associates data with common coordinates and time received from sensors and then performs them by the TBD-PHT processing. In this context, two variants of a centralized asynchronous net with association of signals or signal detections are developed and analyzed. The algorithm with association of signals includes two stages. At the first stage, the signals received from sensors are non-coherently accumulated in the signal matrixes of the fusion centre, because the size of signal matrixes and their cells are the same for the

entire radar net. At the second stage the accumulated signals are transferred into the GOS. The algorithm with association of signal detections firstly accumulates decisions for signal detection after CFAR processing in each sensor, secondly - transfers detections in the GOS. These different types of multi-sensor TBD-PHT processors that operate in the presence of RAII have been developed and studied in (Garvanov et al., 2007; Kabakchiev et al., 2007; Kabakchiev et al., 2007; Kabakchiev et al., 2008; Garvanov et al., 2008).
The expressions for calculating the probability characteristics, i.e. the probability of target detection, trajectory estimation and the false alarm probability, are derived under the assumption that both target coordinates (range and azimuth) and both parameters of the Hough parameter space (ρ and θ) are measured with or without errors. The results obtained show that the detection probability of multi-sensor centralized TBD-PHT processors is higher than that of the decentralized detectors.
The performance evaluation of multi-sensor TBD-PHT processors has been carried out by Monte-Carlo simulations in MATLAB computing environment. The DPA based Hough detector is close to the potential of the most effective multi-sensor CSA Hough detector. The target coordinate measurement errors in the (*r-t*) space mitigate the operational efficiency of multi-sensor Hough detectors. The needed operational efficiency requires the appropriate sampling of the Hough parameter space.
The chapter includes the following paragraphs - abstract, introduction, Single-channel Hough detector in condition of RAII, Performance analysis of a conventional single-channel Hough detector with a CFAR processor, Performance analysis of a single-channel polar Hough detector with a CFAR processor, Multi-sensor (multi-channel) polar Hough detector with a CFAR processor, performance analysis of a multi-sensor polar Hough detector with a CFAR processor and finally conclusion.

2. Single-channel Hough detector in a local RAII environment

2.1 Conventional Hough detector

The basic concept of using the HT to improve radar target detection in white Gaussian noise is firstly introduced in (Carlson et al., 1994). According to this concept, it is assumed that a target moves in a straight line within in a single azimuth resolution cell. The structure of a Hough detector proposed by Carlson is shown in Fig. 1. The Hough detector estimates trajectory parameters in the Hough parameter space that constitute a straight line in the (*r-t*) space.

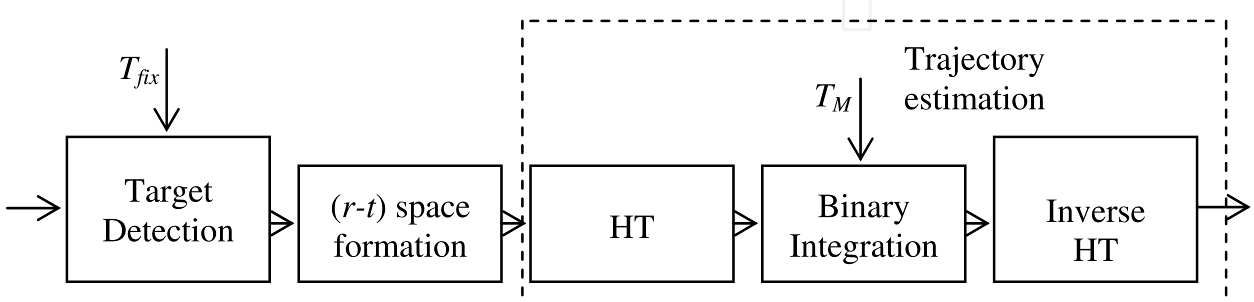

Fig. 1. Structure of a conventional Hough detector with two fixed thresholds

Naturally, two or more large interference spikes in the signal data plane can also constitute a straight line and can create false alarms (false tracks). The control of false alarms in the Hough detector begins with setting an appropriate threshold T_{fix} for signal detection and formation of the (*r*-*t*) space. The (*r*-*t*) space is divided into cells, whose coordinates are equal to the range resolution cell number - in the range and to the scan number in the history - in the time. The HT maps points from the observation space termed as the (*r*-*t*) space, into curves in the Hough parameter space called as the (ρ-θ) space, by:

$$\rho = r\cos\theta + t\sin\theta \quad (1)$$

Here *r* and *t* are the measured distance to the target and time, respectively. The mapping can be viewed as the sampling of θ in the range of 0° to 180° and then the calculating of the corresponding parameter (ρ).
The result of transformation is a sinusoid with magnitude and phase depending on the value of the point in the (*r*-*t*) space. Each point in the Hough parameter space corresponds to one straight line in the (*r*-*t*) space with two parameters (ρ ,θ). Each of the sinusoids corresponds to a set of possible straight lines through the point. If a straight line exists in the (*r*-*t*) space, by means of the Hough transform it can be viewed as a point of intersection of sinusoids defined by the Hough transform. The parameters ρ and θ define the linear

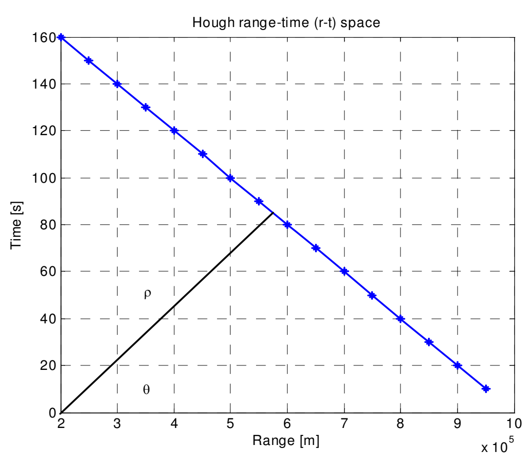

Fig. 2. Range-time (*r*-*t*) space

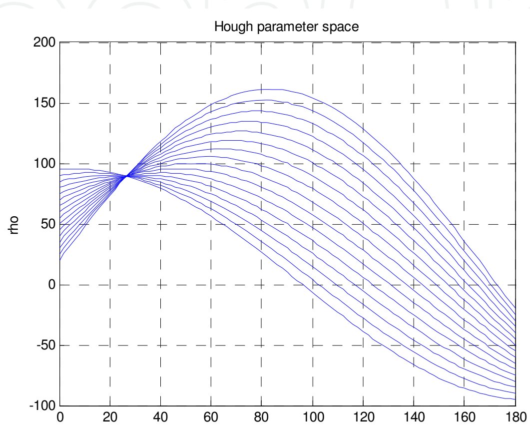

Fig. 3. Hough parameter (ρ-θ) space