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Sensitivity of Track before Detect Multiradar System Toward the Error Measurements of Target Parameters

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Abstract: *In this paper the problem of data association in track-before detect (TBD) multiple radar system is studied in the presence of randomly arriving impulse interference (RAII), and the target coordinates (range and azimuth) are measurable with errors. The usage of the Hough transform (HT) in systems for air traffic control enables the more efficient detection of the target trajectory in the presence of RAII. In the paper, the sensitivity of TBD multi-radar system is investigated as a function of the errors of target trajectory parameters measurement. The influence of trajectory parameter accuracies on the quality of work of TBD multi-radar system is estimated. The study of the signal processing used in detectors is performed with the help of Monte-Carlo simulations in MATLAB computing environment.*

Key words: *Radar net, multi radar system, signal processing, polar Hough transform, track-before-detect, randomly arriving impulse interference (RAII).*

1. Introduction

The data association problem is of major importance in the process of building up a multiple sensors system for detection of a target and trajectories. The data association problem can be mathematically formulated as a well-studied assignment problem. Conventional approaches for data association in a fusion center of the multi-radar system are the centralized and the decentralized approach [1–3]. In the present paper a new multisensor data association approach is proposed, which uses the polar Hough transform (PHT). The polar Hough transform is considered as a track initiator in a track-before-detect (TBD) system. The study is performed in the presence of impulse interference. The algorithm under study includes a parametric CFAR detector, which works successfully in conditions of impulse interference and uses the polar Hough transform. In contrast to the HT, proposed by Carlson, Evans and Wilson in [4], the polar Hough detection algorithm considered in the paper is very efficient for tracking and detection of the target, because the input parameters of the transform are the output parameters of the search radar [5–7].

The presence of randomly arriving impulse interference in radar resolution cells can cause drastic effectiveness degradation of the CFAR processor and Hough detector. False alarms caused by impulse noise make difficult the track detection. The improvement in target and trajectory detection in non-homogeneous background (impulse interference) is possible by using the HT for CFAR detection. In our previous research different types of CFAR Hough detectors, operating in the presence of randomly arriving impulse interference, were studied under the assumption, that the target trajectory parameters (rho and theta) are defined without errors. In this case the target detection was improved [8-12].

It is known that the target coordinates (range and azimuth) are measurable with errors in real radar systems. This leads to errors in the target trajectory parameters (rho and theta) determination. These errors depend on the Hough parameter space discretization [13-15]. The size of cells in the Hough parameter space is better because the errors of measuring target coordinates (range and azimuth) are larger. On the other hand, this brings larger errors in the target trajectory parameter determination.

The task of detection of a target trajectory by different radars is reduced to data association in a TBD multi-radar system. The advantages and disadvantages of the two, centralized and decentralized, three-censored TBD detectors, which use polar Hough transform in case of missing measurement errors, were invesigated in [7].

In this paper the influence of measurement errors provided with censors on the quality of detection in the asynchronous centralized three-censored TBD detector is studied under the assumption that all three censors have the same measurement errors. The coordinate measurement errors (range, azimuth) degrade accumulation of a signal in each cell of the Hough space, i.e. reduce the output SNR and the output signal peak while increasing the output side lobes peak. In that case, reducing the Hough space parameters and optimizing the threshold of detection can maximize the output SNR. Unlike the traditional approach that assumes maximization of the output signal peak, we propose maximization of the output signal "volume" because in that case the accumulation in the Hough space can be more effectively used through, for example, binary integration in each detected channel of the Hough parameter space. For this reason, the purpose of our study is to estimate the sensitivity of one of the maximized output signal parameters (magnitude) and the number of detected channels, towards the values of measurement errors provided by censors at the output of the asynchronous three-censored TBD detector. The maximized output signal is obtained after intuitive parameter optimization of the Hough detector.

2. Signal model

It is assumed that the target is fluctuating according to Swerling II case. It is also assumed that the total background environment includes two situations: (i) – Poisson interference plus noise, which may appear at the receiver input with a probability of e_0, and (ii) – noise only – with a probability of $1 - e_0$. The probability density function (pdf) of the signal power is given in [16] and used in [7-12].

(1) $$f\left(x_0\right)=\frac{1-e_0}{\lambda_0\left(1+S\right)}\exp\left(\frac{-x_0}{\lambda_0\left(1+S\right)}\right)+\frac{e_0}{\lambda_0\left(1+I+S\right)}\exp\left(\frac{-x_0}{\lambda_0\left(1+I+S\right)}\right),$$

where λ_0 is the average power of the receiver noise, I is the average interference-to-noise ratio (INR) of impulse interference, S is the average signal-to-noise ratio (SNR).

3. Netted radar Hough detector

The researched TBD radar system includes three transmitting and receiving stations. A block diagram of a netted Hough detector is presented on Fig. 1. This scheme has parallel topology, which is most widely used. The signal processing in each receiving station includes optimum linear filtration, square law detection (SLD), CFAR detection and plot extraction (PE).

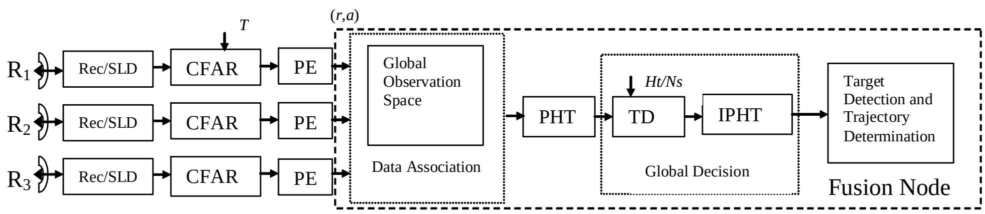


Fig.1. Netted radar Hough detector

The algorithm proposed for signal processing in the paper, is the improved version of the algorithm for target detection and track initiation with the Hough transform, proposed by C a r l s o n, E v a n s and W i l s o n [4]. In order to keep the constant false alarm rate in conditions of randomly arriving impulse interference, in the range-azimuth-time space, signal detection is carried out by a CFAR detector instead the detector with a fixed detection threshold. The CFAR processor is a detector, which maintains a constant false alarm probability in the process of target detection. In such a detector, target detection is declared if the signal sample x_0 exceeds a preliminary determined adaptive threshold.

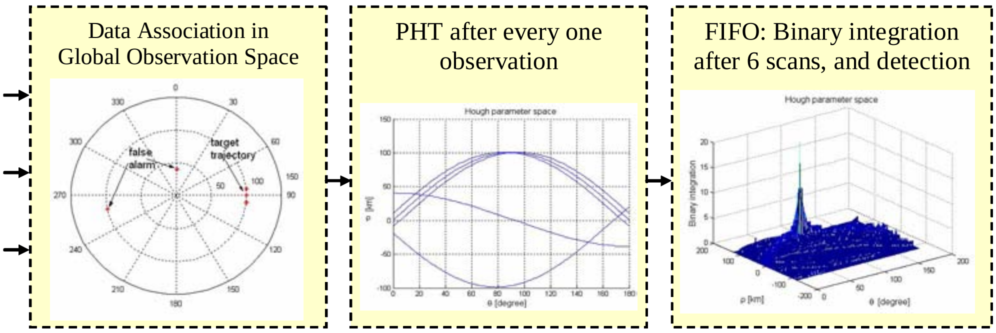
The structure of the research algorithm is presented in Fig. 2. After each radar scan, each of the radars forms the local polar data space (r_n, a_n), where $r_n \in \left[0, r_n^{\max}\right]$ and $a_n \in \left[0, 360^0\right]$ are the target range and azimuth, respectively of the N-th radar. All co-ordinate systems are oriented to the “North”, and the earth curvature is neglected. The first stage is data association of the N-th radar co-ordinate systems to the global range-azimuth co-ordinate system. The second stage is a polar Hough transform.

The PHT maps points (targets) from every one associated local observation space (associated data map) into curves in the Hough parameter space, termed as the $\rho-\theta$ plane, by

(2) $$\rho = r_n \cos\left(a_n-\theta\right),\ 0 < a_n-\theta \le \pi,$$

where the parameter ρ represents the smallest distance between the line trajectory and the origin of the global polar co-ordinate system, while θ is the angle of the vector from the origin to this closest point. If a line trajectory exists in the global

$r - a$ space, by means of polar Hough transform it is represented as a point of intersection of sinusoids defined by PHT. The parameters ρ and θ present the linear trajectory in the Hough parameter space and can be transformed back to the global data space showing the current distance to the target. If the number of binary integrations (BI) of data in the Hough parameter space (of intersections in any of the cells in the parameter space) exceeds the detection threshold, both target and linear trajectory detections are indicated.



FFF. 2. The structure of research algorithm

If radars in the three-censored TBD detector measure the range and azimuth without errors, the sinusoids will be intersected in one cell in Hough space. The size of discretization defines the shape of the obtained platform. If the range and azimuth are measured without errors, the smaller size of accumulation cells will lead to smaller shape of the platform and the pronounced peak in the Hough space (Fig. 3); the larger accumulator size will lead to the larger platform in the Hough space (Fig. 4).

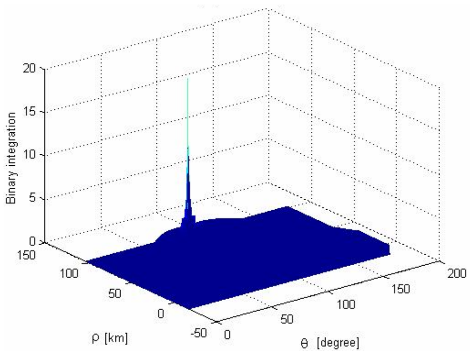


Fig. 3. Hough parameter space: acc(r)=0 m, acc(a)=0 °, $\delta(\rho)$=100 m, $\delta(\theta)$=0.1°

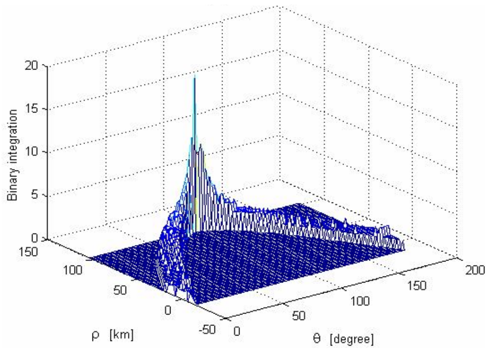


Fig. 4. Hough parameter space: acc(r)=0 m, acc(a)=0°, $\delta(\rho)$=500 m, $\delta(\theta)$=1°

In a real radar system it is known that the target coordinates (range and azimuth) are measured with errors [15]. The radars measurement errors (accuracy) $\mathrm{acc}(r_n)$ and $\mathrm{acc}(a_n)$ can be expressed as measurement oscillations around the considered trajectory. We assume a normal distribution for $\mathrm{acc}(r_n) \approx N(0,\sigma_r^n)$ and $\mathrm{acc}(a_n) \approx N(0,\sigma_a^n)$ [13], where σ_r^n, σ_a^n are the standard deviations of the measurement errors.

The measurement errors (σ_r^n and σ_a^n) of the co-ordinates (r_n, a_n) decrease the binary integration in accumulator cells in the Hough space. In this case, the sinusoids of one linear trajectory will be intersected in different accumulator cells. The correspondence between the Hough parameters (ρ, θ and their discretization $\delta\rho$, $\delta\theta$) and polar range-azimuth space is shown in Fig. 5.

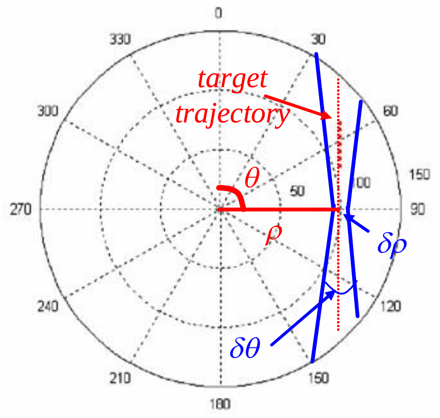


Fig. 5. Hough parameters

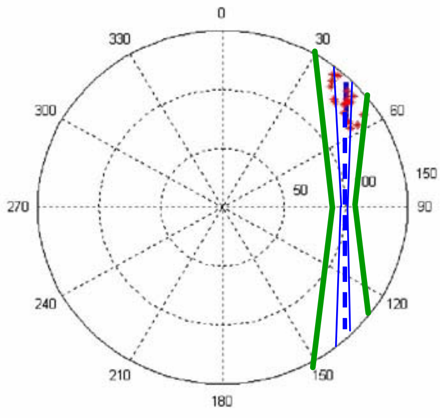


Fig. 6. Hough parameter space: acc(r)=500 m, acc(a)=1°

In order to obtain maximal integration (peak), it is necessary to increase the size of the accumulator cells in the Hough space ($\delta\rho$, $\delta\theta$), but this leads to larger errors of ρ and θ (Figs. 6, 7 and 8). Also availability on false alarms will increase the platform. The strip defined by the "maximal" values of these errors has got a complicated shape depending on the measurement coordinates (Fig. 5). Our hypothesis is to maximize the "volume" of the output signal, because in that case the accumulation in the Hough space can be more effectively used through, for example, binary integration in each detected channel of the Hough parameter space. The purpose of this study is to investigate the dependence between the measurement accuracy of the censors and the number of the accumulated (detected) channels at the output of the asynchronous centralized three-censored TBD detector, after intuitive parameter optimization of the Hough detector.

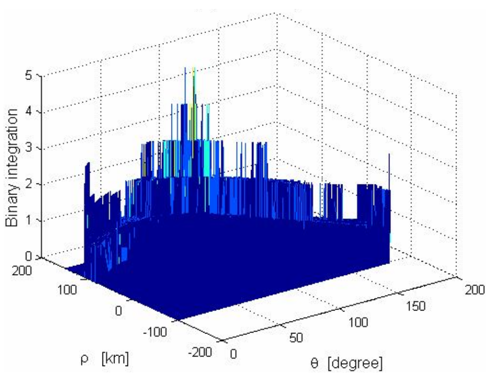


Fig. 7. Hough parameter space: acc(r)=500 m, acc(a)=1°, $\delta(\rho)$=500 m, $\delta(\theta)$ = 0.5°

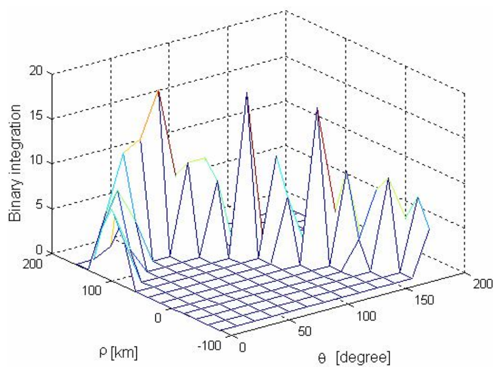


Fig. 8. Hough parameter space: acc (r)=500 m, acc (a)=1°, $\delta(\rho)$ = 2000 m, $\delta(\theta)$ = 15°,

The Polar Hough Transform is only efficient if a high number of radar measu-rements fall in the right range-azimuth area which correspondence of one accumulator cell in Hough space, so that the binary integration can be easily detected amid the background noise. This means that the accumulator cell must not be too small, or else some radar measure will fall in the neighboring Hough cells, thus reducing the visibility of the main cell.

Besides this, much of the efficiency of the Polar Hough Transform is dependent on the quality of the input data: the edges must be detected well for the PHT to be efficient. Use of the PHT on noisy background (presence of false alarm) is a very delicate matter and generally, more radar measurements are necessary, since it has the nice effect of attenuating the noise through summation.

The correspondence between the accumulator cells in Hough space and the polar range-azimuth space is shown in Fig. 9. For example, the binary integration of every cell in Hough space is obtained from a trajectory in the corresponding area in the range-azimuth space. In analogy with this, every cell is obtained from a given area in the range-azimuth space. On Fig. 9 two situations are shown, when ρ is constant (case 1) and when θ is constant (case 2). The increasing of the value of accumulator cells leads to bigger probability for presence of trajectory in the obtained range-azimuth area. Also this will lead to bigger cover area in the range-azimuth space and the radar measurements will fall in the neighboring Hough cells. In this case the peak will increase, but the platform will also be increased.

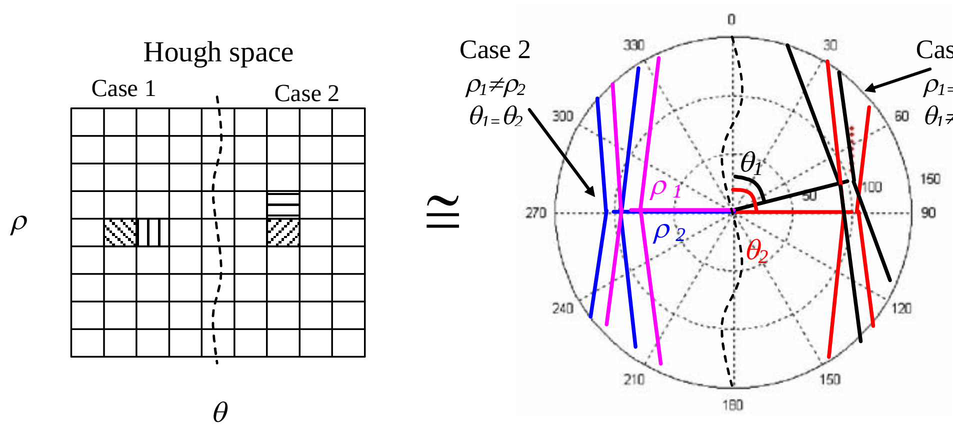


Fig. 9. Every cell from Hough space corresponds to an area in the range-azimuth space

In the real radar system, the target coordinates (range and azimuth) are measu-rable with errors. The radars measurement errors (accuracy) can be expressed as measurement oscillations around the considered trajectory.

In order to obtain maximal integration (peak), it is necessary to increase the size of the accumulator cells in the Hough space, but this leads to larger errors of ρ and θ.

4. Simulation example and experiment description

The examples illustrate the advantages of the netted radar that operates in the presence of randomly arriving impulse interference.

The radars are with one and the same power and the same technical parameters. Their positions form the equilateral triangle where the lateral length is 100 km. The radar technical parameters are: the search scan time is 6 s; the range accuracy acc(r) = 0, 100, 500 m; the azimuth accuracy acc(a) is 0° and 1°. The experimental results are obtained for the following input parameters: target speed is Mach 1 and m^2 radar cross section, fluctuating target of Swerling II case, the average SNR is calculated as $S=K/R^4 \cong 15$ dB, where $K = 2.07.10^{20}$ is the generalized energy parameter of the radar and R is the distance to the target measured; the average power of the receiver noise $\lambda_0= 1$, the average interference-to-noise ratio is r_j=10 dB, the probability of appearance of impulse noise is 0.033. The number of CFAR reference cells is N=16; the probability of false alarm in Hough parameter space is $P_{FA}= 10^{-2}$, the number of scans is $N_s = 6$. The size of the cells in Hough parameter space is $\delta(\rho) = 0.1$-4 km, $\delta(\theta)$ is equal to 0.5°, 1°, 2°. The binary detection threshold in Hough parameter space is $H_t = 10$.

After 6 radar scans and data association toward the global co-ordinate system we perform the polar Hough transform. The influence of the cell size in the Hough space on the effectiveness of binary integration is studied for different measurement errors of range and azimuth. In order to maintain constant binary integration in the Hough space when increasing the distance measurement errors, it is necessary to increase the size of the accumulator cells (Fig. 10).

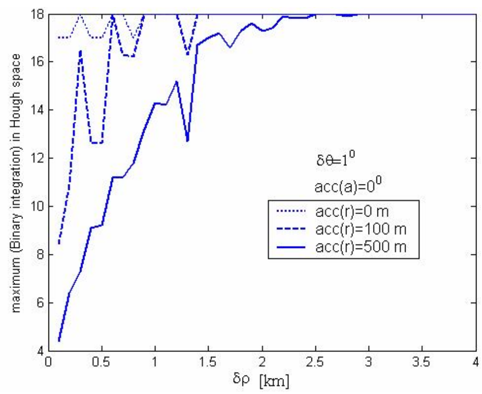


Fig. 10. Hough parameter space: acc(r) = 0, 100, 500 m, acc(a) = 0°, $\delta(\rho) = 0.1$-4 km, $\delta(\theta) = 1°$

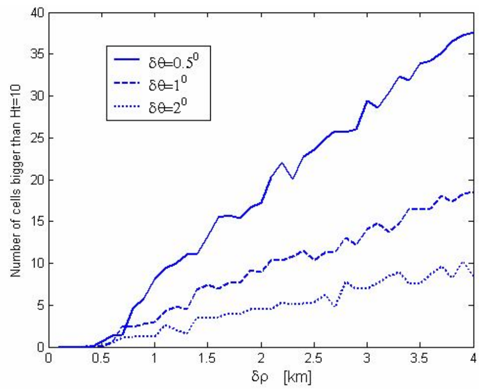


Fig. 11. Hough parameter space: acc(r) = 500 m acc(a) = 0°, $\delta(\rho) = 0.1$-4 km, $\delta(\theta) = 0.5$, 1, 2°

The increase of the Hough threshold leads to the decrease in the number of cells, which exceed the threshold. The range measurement errors influence essentially the maximal output signal peak, while the influence of the azimuth errors is less significant (Fig. 10). The number of the cells from the platform (exceeding the Hough threshold) depends both on the size of cells in the Hough space (Fig. 11) and on the value of the Hough threshold. The increase of ρ leads to the increase in the number of cells, which exceed the detection threshold. The increase of θ leads to the decrease of this number. When the Hough threshold increases, the numbers of the exceed cells decreases.

5. Conclusion

In this paper the influence of the sampling of the Hough space for different accuracy characteristics of the synchronic centralized three-censored TBD system is investigated. In order to maintain constant binary integration in the Hough space when increasing the measurement errors of range and azimuth, it is necessary to increase the size of the accumulator cells. We recommend choosing the size of discretization of the Hough space to be twice larger than the maximal measurement error of the target co-ordinates. The study is carried out using Monte-Carlo simulations in MATLAB computing environment.

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