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Bi-station Multi-target Tracking Using Range and Doppler Measurements

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Abstract. The azimuthal measurements of the high frequency ground wave radar are poor in an actual environment, which can cause the plots highly decentralized and damage the formation of the over-the-horizon tracks. To solve the problem, a new radar system is proposed to triangulate target tracks using range and Doppler measurements only. On the basis of the analysis of the characteristics of the range-finding location, a multi-target tracking algorithm under non-clutter condition is given in this paper, which further improves the tracking algorithm of this system. Simulation results show the effectiveness of this method.

Introduction

The bearing observations of the radar are often fuzzy, random and defect when the modern battlefield environment is complex and poor, which cause serious damage to the practical performance of the radar. Therefore, the research of locating and tracking using only range and Doppler measurements is very meaningful for radar real applications [1-3].

Some research has been done for the track-before-detection of locating and tracking using only range and Doppler measurements by Deming, R. W et al.[4-6]. A new bi-station OTH radar system has been proposed recently which use range-finding location for track-after- detection for the first time[7]. In paper[7], A HF ground wave bi-station system is proposed to locate the target tracks using only range and Doppler measurements. The locating and tracking model is established and the extended Kalman filter (EKF) is used to solve the bi-station nonlinear tracking problem. And it also points out that this system has two key issues: One is how to use range-finding location to track target, the other is data association. Paper[7] solve the first one. Paper[8] discuss the location accuracy of the bi-station OTH radar system. The error model is established and the Geometrical Dilution of Precision (GDOP) in the whole observation region are presented. The GDOP distributions under different location arrangement conditions are also discussed in paper[8].

This paper mainly discusses the second key issue of the range-finding location bi-station radar system which has not been solved before. Under non-clutter condition, the data association method of the bi-station OTH radar system is divided into three steps and the key is how to handle the ghost just like the passive location. The first step is based matching method of plot-to-track and rule-based tracking methodology. The second step is the method of the eliminating ghost targets by estimating the speed of the target using only one radar's observations and calculating the change in target's angle by two adjacent observations. The third step is to turn the two steps ahead into a 0-1 programming problem to get the final result of the association problem. The simulation results show the effectiveness of this method.

Multi-target Tracking Algorithm By Range-finding Location

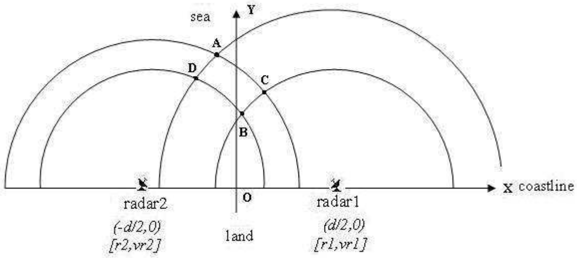

Figure.1 The ghost of range-finding location

Fig.1 shows that range-finding location method uses the radar's location as the center of a circle separately and the range observation as the radius of the circle. In the simplest case, there are two targets A and B in Fig.1, but the range-finding location method will inevitably produce two ghost plots C and D. It is similar to the direction-finding location. However, we cannot use the traditional methods such as static method and dynamic method[9] because there is no redundancy of observation and the ghost can get steady tracks. We need to get supplementary information from single radar's range and Doppler measurements and compare those of the two stations to distinguish ‘ghost tracks’. This paper will focus on this problem.

From what we have discussed above, the multi-target tracking using range-finding location needs new method. In this section, the method is divided into three steps:

Step1: Plot-to-track and rule-based tracking methodology. In order to minimize the amount of calculation, learn the method of NJPDA, a plot-to-track is given here. Define associated threshold: $[Z(n+1)-\hat{Z}(n+1\mid n)]^T S^{-1}(n+1)[Z(n+1)-\hat{Z}(n+1\mid n)]\le\gamma$. Z(n+1) is the measured value at time n+1,$\hat{Z}(n+1|n)$ is the predictive measured value at time n. S(n+1) is the innovation covariance at time n+1. γ is the associated threshold, which is according to the measurement noise and system parameter to set.

Define plot-to-track associated value matrix R$\in\boldsymbol{R}^{N\times M}$. N is the number of the track and M is the $[Z(n+1)-\hat{Z}(n+1\mid n)]^T S^{-1}(n+1)[Z(n+1)-\hat{Z}(n+1\mid n)]\le\gamma$ number of plot which is associated with every track:

$$\begin{array}{cc} & \longrightarrow \text{plot} \\ R= & \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & n_{n2} & \cdots & r_{nm} \end{bmatrix}\downarrow\text{track} \end{array} \qquad \begin{array}{cc} & \longrightarrow \text{plot} \\ \mathrm{D}= & \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix}\downarrow\text{track} \end{array}$$

The row of the matrix R of represents the track number and the column represents the point which associated with the track. The number of the plots is M. Here predetermined that the previous element in the same row is always greater than the latter element which means that the previous element always have the greater degree of association of the track. Therefore, the first column of the matrix R has the maximum degree of association. The element r_{ij} represents the degree of association of plot i and track j: $r_{ij}=[Z(n+1)-\hat{Z}(n+1\mid n)]^T S^{-1}(n+1)[Z(n+1)-\hat{Z}(n+1\mid n)]$

Define plot-to-track associated address matrix D$\in R^{N\times M}$. N is the number of the track and M is the number of plot which is associated with every track. The element d_{ij} represents the number of plot j which is associated with track i.

The plot-to-track associated address matrix D has the same size of the plot-to-track associated value matrix R. r_{ij} represents the association value of the plot which designated by d_{ij}.

The association processing is divided into two steps as follow:

The first step is to construct matrix R and D by the existing track information and observations. From these two matrixes, we can know that every plot is associated with a track and the degree of association. The second step is pairing process. At first, we search the first column of matrix D to see if there have the same elements. If it does not , that means the association of the plot and track is unique and the problem of the multiple points associate with one track is also been solved. Otherwise, we have to compare the value of the association in the matrix. Learning from paper[10], we give the rule-based algorithm for the track start, maintain and cancel rule.

Rule 1: At the beginning of the observation, if the plots can associated in two consecutive cycles, that generates a temporary track. Because we cannot distinguish the true targets form the ghosts at the beginning of the observation.

Rule 2: Track confirmation is effective when the number of the consecutive cycles reaches three. After the track confirmation, the track Initiation ends.

Rule 3: If the temporary track does not receive an observation in one cycle, it would not been deleted. The predictive value will be seen as filtered value.

Rule 4: If the temporary track does not receive an observation in more than two cycles, it has to be deleted.

The flow chart of the bi-station multi-target tracking algorithm based these four rules is given below:

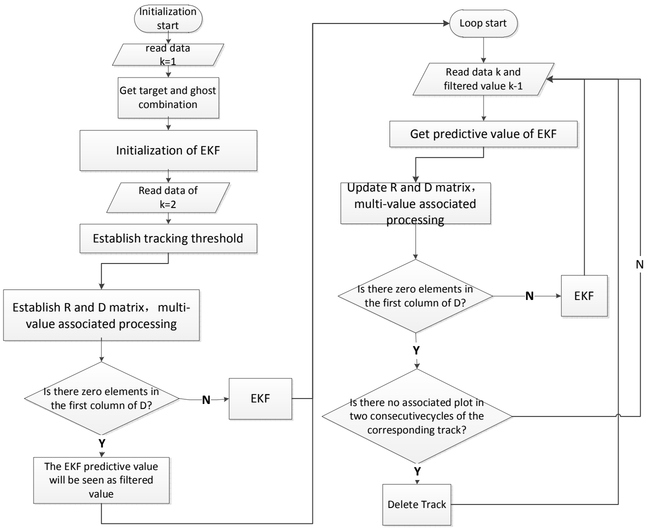

Fig. 2 The flow chart of multi-target tracking algorithm based these four rules

Step2: Eliminate ghost targets by using only one radar's observations and calculating the change in target's angle by two adjacent observations. When it comes the formation tracks, the step 1’s results are unsatisfactory. Because under that condition, the ghost and real targets are quite similar, we must extract the differences between them further on the basis of step1. And this can be seen as an extension of the threshold.

The essential difference between the ghost and the real target is the combinatorial problems. Therefore if each sensor can get a feature of the target differently, the problem will be solved. Fortunately, using one sensor’s range and Doppler observations we can get the targets’ speed information by deducing. And after step1, the number of the targets and the ghost can be roughly determined. Using that conclusion, we can estimate the ghost by the following method.

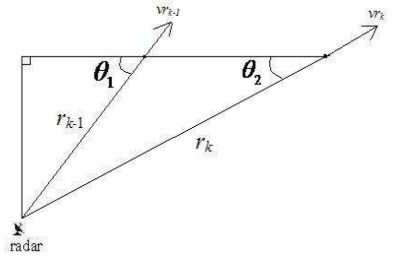

Figure.3 Using one sensor's range and Doppler observations to get the targets' speed information

In fig.3, r_{k-1} and r_k represent the range observation of the target by time k-1 and k, vr_{k-1} and v_{rk} represent the Doppler observation of the target by time k-1 and k, and V is the speed of the target.

$$\begin{cases} r_{k-1}\cdot\sin\theta_1 = r_k\cdot\sin\theta_2 \\ vr_{k-1} = V\cdot\cos\theta_1 \\ vr_k = V\cdot\cos\theta_2 \end{cases} \Longleftrightarrow \begin{cases} r^2_{k-1}\cdot\sin^2\theta_1 = r_k^2\cdot\sin^2\theta_2 \\ vr^2_{k-1} = V^2\cdot\cos^2\theta_1 = V^2\cdot(1-\sin^2\theta_1) \\ vr^2_k = V^2\cdot\cos^2\theta_2 = V^2\cdot(1-\sin^2\theta_2) \end{cases} r_{k-1}^2\left(1-\frac{vr_{k-1}^2}{V^2}\right) = r_k^2\left(1-\frac{vr_k^2}{V^2}\right) \quad (1)$$

Then we can get:

$$|V| = \sqrt{\left|\frac{vr_k^2\cdot r_k^2 - vr_{k-1}^2\cdot r_{k-1}^2}{r_k^2 - r_{k-1}^2}\right|} \quad (2)$$

From the above, we can use (2) to distinguish the ghost and the real target when the targets have different speed. For the same speed target, we can use the following method:

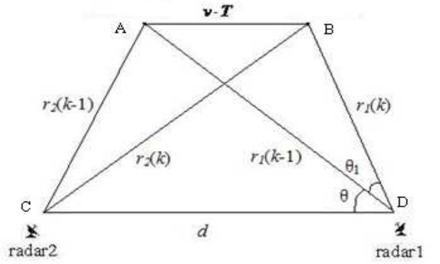

Fig. 4 Azimuth change of the target in two cycles

The former method inspired us that if the feature of a target can be get form one sensor and two sensors separately; the ghost can be find because of it cannot simultaneously satisfy both conditions.

In fig.4, θ_1 is the azimuth change of the target between cycle k-1 and k and the time is T. The speed of the targets is V and the distance between the two stations is d.
By using the law of cosines in triangle ACD, triangle BCD and triangle ABD, we can get:

$$\begin{cases} d^2 + r_1^2(k-1) - 2d\cdot r_1(k-1)\cdot\cos\theta = r_2^2(k-1) \\ d^2 + r_1^2(k) - 2d\cdot r_1(k)\cdot\cos(\theta+\theta_1) = r_2^2(k) \\ (VT)^2 = r_1^2(k-1) + r_1^2(k) - 2r_1(k-1)\cdot r_1(k)\cdot\cos\theta_1 \end{cases} \quad (3)$$

From the first two formulas and the last one in (3), we can get:

$$\theta_1 = \left|\arccos\left(\frac{d^2+r_1^2(k)-r_2^2(k)}{2d\cdot r_1(k)}\right) - \arccos\left(\frac{d^2+r_1^2(k-1)-r_2^2(k-1)}{2d\cdot r_1(k-1)}\right)\right| = \arccos\left(\frac{r_1^2(k-1)+r_1^2(k)-(VT)^2}{2r_1(k-1)\cdot r_1(k)}\right) \quad (4)$$

Now we get two different ways to calculate θ_1. The real target should satisfy (4), but the ghost should not.

Step3: 0-1 programming

Further analysis of the nature of the ghosts, N targets can have N2 different combined observations at most and we can have N! different possible choices to get N tracks. But only one choice is right and that makes this problem into a 0-1 programming problem in math. Therefore we can use this math tool to solve the problem at the last step.

Define track association event matrix B:

$$\begin{array}{ll} \longrightarrow radar2 & \\ \begin{matrix} \quad 1 & \quad 2 & \quad \cdots & N \end{matrix} & \\ \begin{bmatrix} b_1 & b_2 & \cdots & b_N \\ b_{N+1} & b_{N+2} & \cdots & b_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ b_{N^2-N+1} & b_{N^2-N+2} & \cdots & b_{N^2} \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ \vdots \\ \mathrm{N} \end{matrix} \downarrow radar1 \end{array}$$

The value of b_j represents whether the track j has been deleted. $b_j=0$ means deleted, or $b_j=1$. The matrix B is the final tool to judge the observing combination is right or wrong. After several cycles, according to the step 1 and 2, we can get matrix B and it gives the all possible combinations of targets at this time. Then we must make sure that there is only one nonzero element in each row and column. If the result of that is unique, the problem is solved, or we have to use the track correlation value matrix C for further processing.

Define track correlation value matrix C:

$$\begin{array}{ll} \longrightarrow radar2 & \\ \begin{matrix} \quad 1 & \quad 2 & \quad \cdots & N \end{matrix} & \\ \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1N} \\ c_{21} & c_{22} & \cdots & c_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ c_{N1} & c_{N2} & \cdots & c_{NN} \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ \vdots \\ \mathrm{N} \end{matrix} \downarrow radar1 \end{array}$$

c_{ij} is the accumulated amount innovation of the NO. i×N+ j track from start to cycle K and if the track has been deleted, c_{ij} can be defined a very large number. The correspondence relationship between C and B is just like R and D. Therefore we can use C to turn the problem into a 0-1 programming problem:

$$\mathbf{min}\sum_{i=1}^{N}\sum_{j=1}^{N} c_{ij}x_{ij}\,; \tag{5}$$

$$\mathbf{s.t.}\sum_{i=1}^{N} x_{ij} = 1, \qquad j = 1,2,\cdots N \tag{6}$$

$$\sum_{j=1}^{N} x_{ij} = 1, \qquad i = 1,2,\cdots N \;\; x_{ij} = 0 \;\; or \;\; 1 \qquad i,j = 1,2,\cdots N$$

The final result is given by the x_{ij} whose value is 1 and the corresponding number of x_{ij} is the real track number. Now the whole algorithm process is done.

Simulation Results

Based on the discussions above, we will provide the simulation results to support the theoretical development in the previous section. The simulation conditions are almost the same as section 3: There were 4 ship targets sailing as same speed in the sea. The targets make uniform motion, start at （-45,155），（-45,170），（-45,185）and（-45,200）with the X-axis positive direction into the -55 degree. The speed of the targets is 20km/h and the observation cycle time is 200s with measuring 100 cycles. $\sigma_{r1} = \sigma_{r2} = 2km$, $\sigma_{vr1} = \sigma_{vr2} = 5m/s$ The two radar stations are located at the X-axis and symmetrical about the origin, (-50,50). That is 100km from each other. The results are shown in fig.5:

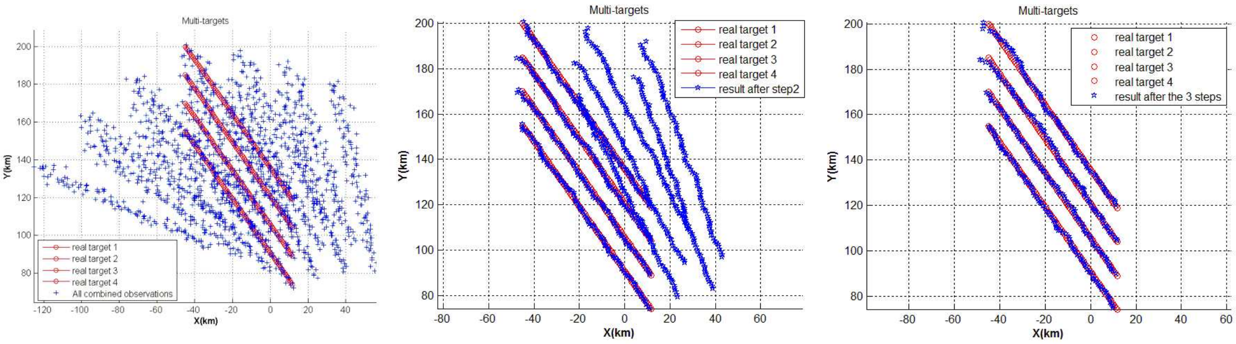

Fig. 5 The real targets and the ghosts, the result after step 2 and the final result

The simulation result shows that the multi-target tracking algorithm in this paper is effective and it can handle the ghost well.

Conclusions

This paper mainly discusses the second key issue of the range-finding location bi-station radar system which has not been solved before. Under non-clutter condition, the data association method of the bi-station OTH radar system is divided into three steps: The first step is based matching method of plot-to-track and rule-based tracking methodology. The second step is the method of the eliminating ghost targets by estimating the speed of the target using only one radar's observations and calculating the change in target's angle by two adjacent observations. The third step is to turn the two steps ahead into a 0-1 programming problem to get the final result of the association problem. The simulation results show the effectiveness of this method.

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