TOA Data Association Based on Peak Detection of Reconnaissance Region

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Abstract: To solve the problem that the permutation and combination in the traditional data association algorithms result in a high computational cost, this paper proposed a novel TOA data association algorithm based on the peak detection of reconnaissance region. Firstly, some samples of the TOA curves can be obtained by azimuth searching, and then the data association problem can be transformed into a 2-dimensional detection problem by blurring and adding the curves. The simulation results show that the proposed algorithm can improve the computational efficiency with hardly reduce of the correct association probabilities, implying good application prospect.

Key words: External illuminator based passive radar; Time of arrival measurement; Multi-sensor data association; Multi-dimensional assignment

1. Introduction

External illuminator based passive radar is a detect system which do not radiate electromagnetic waves by itself but utilize the existing waves in the airspace to detect targets [1]. Target locating and tracking are the main functions of the external illuminator based passive radar. The common locating methods include direction of arrival (DOA), time of arrival (TOA), and time difference of arrival (TDOA) locating methods [2].

The TOA location also named ellipse location. The TOA measurements of the echo signals from different transmitters can be described by several ellipses, and the intersect point of the ellipses is the estimation of the target position. When we use multiple-transmitter single-receiver system to perform TOA location, the main problem is determining which ellipses are corresponding to the same target, namely TOA data association problem, which is a hot and difficult topic in the research area of the multi-sensor fusion systems [3].

The TOA data association problem can be described as a S-D assignment problem. Because the number of candidate pairs are exponentially increased with the problem dimension. Searching the optimum solution by exhaustive listing of all the possible pairs is NP-hard problem. The Lagrangian relaxation algorithm proposed in [4] changed the S-D assignment problem into a series of 2-D assignment problem by successively relaxing and enforcing with some constraints. Recently, An improved relaxation algorithm is proposed in [5], which selected some corrected pairs without redundant relaxations by the statistical test based on the indicator function, so the computational efficiency can be improved. However, all the algorithms mentioned above should build the candidate tree by the permutations and combinations, which limited the further increase of computational efficiency. To solve the problem, this paper proposed a novel method based on the peak detection of reconnaissance region. Firstly, some samples of the TOA curves can be obtained by azimuth searching, and then the data association problem can be transformed into a 2-dimensional detection problem by blurring and adding the curves, so the permutations and combinations can be avoided. The simulation results show that the proposed algorithm can improve the computational efficiency with hardly reduce of the correct association probabilities, implying good application prospect.

2. Proposed data association algorithm

The Lagrangian relaxation algorithm solved the S-D problem by successive relaxation and constraint enforcement, so all the ($S-2$)D constraints are relaxed simultaneously, however, building the candidate

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assignment tree would take a lot of CPU time [6]. Recently, an improved relaxation algorithm is proposed in [5], which selected some corrected pairs without redundant relaxations by the statistical test based on the indicator function, so the computational efficiency can be improved. However, this algorithm also needs to build the candidate assignment tree by permutation and combination with high computational cost. To solve the problem, this section proposed a novel method based on the peak detection of reconnaissance region. Firstly, some samples of the TOA curves can be obtained by azimuth searching, and then the data association problem can be transformed into a 2-dimensional detection problem by blurring and adding the curves, so the permutations and combinations can be avoided.

For simple and universal, we consider an external illuminator based passive radar system consists with S transmitters and 1 receiver in the x-y plane, and the receiver obtained S groups of TOA measurements $\mathbf{z}_{si_s}$ ($i_s = 1, 2, \cdots, n_s$). Assuming that the receiver is the origin of the x-y coordinates, the distance of the target from the receiver is R_r. According to the geometry relationship of TOA location, as shown in Fig. 1, we can get the following equation.

$$R_r \approx \frac{(C\mathbf{z}_{si_s})^2 - L^2}{2C\mathbf{z}_{si_s} - 2L\cos(\varphi_r + \theta_t)} \tag{1}$$

where L is the length of baseline, φ_r and θ_t are the azimuth angles of the target and the transmitter, respectively.

As can be seen from (1), because the position of the transmitter is known, given any azimuth angle φ_r, we can calculate the corresponding distance R_r. Due to the fact that the reconnaissance region of the external illuminator based passive radar system is almost known, we can get the discrete samples of TOA curves by azimuth searching.

Considering the effect of measurement noise $\mathbf{v}_{si_s}$, we use a point spread function in (2) to blur the samples. So several curve segments with certain width and height can be obtained.

$$h_p(\mathbf{X}_q) = \begin{cases} \sum_{s=1}^{S}\sum_{i_s=1}^{n_s} \frac{1}{2\pi\Sigma_{r,s}^2} \exp(-\frac{(x_q - x_{p,i_s})^2 + (y_q - y_{p,i_s})^2}{2\Sigma_{r,s}^2}), & \mathbf{X}_q \in T(\mathbf{X}_{p,i_s}) \\ 0 & , \mathbf{X}_q \notin T(\mathbf{X}_{p,i_s}) \end{cases} \tag{2}$$

where $\mathbf{X}_{p,i_s} = (x_{p,i_s}, y_{p,i_s})^T$ is the target position estimation of the i_s th TOA measurement of the s th measurement set in the p th azimuth searching, $\mathbf{X}_q = (x_q, y_q)^T$ represents any resolve cell in the reconnaissance region, $T(\mathbf{X}_p)$ is the adjacent region of $\mathbf{X}_p$, $\Sigma_{r,s}$ is the standard deviation of distance measurement noise.

$$\Sigma_{r,s} \approx \frac{(2C^2 - C^3)\mathbf{z}_{si_s}^2 - 2CL\cos(\varphi_r + \theta_t)\mathbf{z}_{si_s} + CL^2}{2\left[C\mathbf{z}_{si_s} - L\cos(\varphi_r + \theta_t)\right]^2}\Sigma_s \tag{3}$$

Without measurement noise, different curves should be intersected at the true target position. Because the effect of measurement noise is represented by the point spread function, the thick curves will be intersected in a blurred area, and the true target position will have the max value. So the TOA data association problem can be transformed into a 2-dimensional detection problem, which is unnecessary to go into details any more.

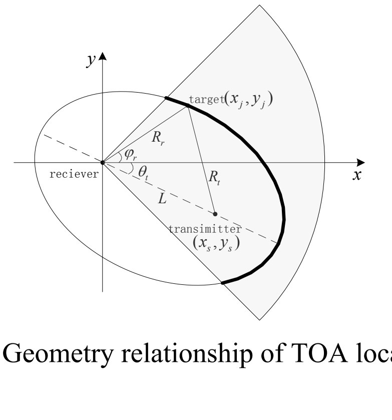

Fig. 1 Geometry relationship of TOA location.

The main idea of the proposed algorithm is changing the computational cost of permutation and combination to the cost of azimuth searching. Thus the computational efficiency can be improved by detecting the peaks rather than building the candidate tree. Suppose that the external illuminator based passive radar system consists of S transmitters and 1 receiver, and each measurement set contains n elements. In [4], it was indicated that the computational complexity of the Lagrangian relaxation algorithm is $O(200(S-1)Cn^3)$, where 200 is the max number of iterations, $C \in (0,1000)$ is the cost coefficient. As can be seen, the computational cost is still high when the number of sensors and targets is large. Suppose that the azimuth range of the reconnaissance region is 90 degree, the search step is 1 degree, the R_r is calculated $S \times n$ th in each azimuth angle, the adjacent region of each search position contains m points, then the computational complexity of the proposed algorithm is $O(90Snm)$, which is much smaller than that of the Lagrangian relaxation algorithm.

3. Simulation results

In this simulation, an external illuminator based passive radar system consists of 6 transmitters and 1 receiver in x-y coordinates is considered. The positions of the transmitters are $(-30,-30)km$, $(-30,30)km$, $(30,-30)km$, $(30,30)km$, $(0,-50)km$, $(0,50)km$, respectively. The position of the receiver is the origin. There are 9 targets in the reconnaissance region. The standard deviation of the TOA measurement noise is $0.1\mu s$, the detect probability is 0.95, and each measurement set contains 5 clutter.

Using the proposed algorithm to search the azimuth range (from 45 to 135 degree, step 1 degree), we can get the discrete curves. After blurring and adding the curves according to the point spread function, we can get the 2-dimensional detection plane that the true target position can be easily extracted by peak detection, as shown in Fig. 2.

To further evaluate the performance of the proposed algorithm, 500 Monte Carlo experiments are made for the algorithm in [5] and the proposed algorithm, respectively. As can be seen from the results shown in Table 1, for the same standard deviation of the measurements, the correct association probabilities of the method in [5] is slightly higher than those of the proposed method with much longer running time. This is due to the fact that there are some approximations in the point spread function of the proposed method while the permutation and combination are avoided by searching the reconnaissance region. For the engineering applications, the proposed algorithm has better prospect than the traditional one.

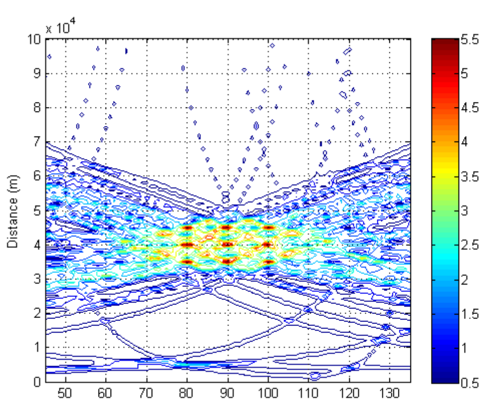

Fig.2 2-dimensional detection plane by blurring and adding the curves.

Table 1 Performance comparison of different algorithms.

	Standard deviation of TOA measurement noise (μs)	Correct association probabilities (%)	Time of each running (s)

Method in [5]	0.1	99.5	362.9
	1	99.1	398.6
	3	75.3	411.7
	6	66.7	422.4
	10	62.6	433.9
Proposed method	0.1	99.4	1.49
	1	98.7	1.77
	3	72.0	1.87
	6	63.4	1.90
	10	60.4	1.95

4. Conclusion

To solve the problem that the permutation and combination in the traditional TOA data association algorithms result in a high computational cost, a novel method is proposed in this paper. Firstly, some samples of the TOA curves can be obtained by azimuth searching, and then the data association problem can be transformed into a 2-dimensional detection problem by blurring and adding the curves, so the permutations and combinations can be avoided. This paper only focuses on the case of 2-dimensional detection problem for simplicity, but the proposed algorithm can be easily extended to the 3-dimensional detection problem by adding the elevation searching besides the azimuth searching.

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