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Performance Analysis on Association Algorithms of Heterogeneous Sensors

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Abstract. Statistical theory and fuzzy analyses are two primary methods in heterogeneous sensors association algorithms. Firstly, absolute-double-threshold rules were used to analyze the algorithms performance of heterogeneous sensors in this paper. Then, both of these two algorithms ware simulated on computer, which based on large data samples. The simulation results show that both of these two track association algorithms has high probability of correct association, but the algorithm based on statistical theory has faster convergent speed and litter samples, while the other is simple, and has less calculation.

Introduction

Data fusion is always an important and difficult problem in heterogeneous sensors data fusion. Data fusion of radar and ESM is the typical case, the fusion result not only obtained accurate parameters (etc. space, speed and properties)of targets, but also can use ESM to inducting radar jamming, which can improve the survive of detection system. The precondition of fusion is track association, which is essential of orientation, track, analyses and recognition [1, 3].

Generally, radar and ESM track association algorithms include statistical theory [4~5] and fuzzy analysis [6~7]. In this paper, double-threshold rule was used to analyze the performance of these two algorithms. The simulation result show that both of these two algorithms has high probability of correct association, but the algorithm based on statistical theory has faster convergent speed and litter samples, while the other is simple, and has less calculation.

Problem Description

As a passive sensor, ESM can only obtain the azimuth and property information of targets, not distance information. While active radar can obtain the azimuth and distance information of targets, not property information. Because of the redundancy information is azimuth, the data association of radar and ESM commonly generally belongs to track association which based on information [1].

Assumption that there are m radar tracks. While one flat can embark multi-radiates and every ESM track correspond one radiate, so one radar tacks can associate many ESM tracks, but each ESM tracks can associate not more than one radar tracks. Thus, the question of m radar tracks and one ESM track can translate to this multi-supposed prove.

H_0: ESM track don't associate to any radar tracks.

H_j: ESM track associate to j radar track, and $j \neq 0$.

The association of multi-radar tracks and multi-ESM tracks based on this assumption hypothesis. In order to predigest discuss, assumption that $\theta_e(t_i)$ is the ESM tracks azimuth in time t_i, $\theta_j(t_i)$ is the no. j radar track azimuth in time t_i and the azimuth error is independence, which obey the Gauss distribution $N(0,\sigma)$,and mean is zero.

Association Algorithm and Judge Rules

Statistical Theory Method

Assumption that H_j is true, then

$$H_j : \varepsilon_j = \frac{\theta_e(t_i) - \theta_j^p(t_i)}{\sqrt{\sigma_e^2 + \sigma_j^2}} \sim N(0,1) \tag{1}$$

Restriction: $\theta_j^p(t_t)$ was smoothly detruded by three-dot in $\theta_j(t_i)$. σ_e is the measured azimuth by ESM, while σ_j by radar j.

Construct statistic d_j and P_j.

$$d_j = \sum_{i=1}^{n_j} [\frac{\theta_e(t_i) - \theta_j^p(t_i)}{\sqrt{\sigma_e^2 + \sigma_j^2}}]^2 \tag{2}$$

$$P_j = Q_j(d_j) = 1 - \int_{d_j}^{\infty} \chi^2(x, n_j)dx \tag{3}$$

n_j is the number of measured azimuths in the time of t, $\chi^2(x, n_j)$ is the probability consistency function of random variety P_j. Apparently, P_j belongs to N (0, 1), and has no association with n_j, thus it can be considered to the judge function of radar and ESM tracks association.

Simulate all p_j, and find out p_s and p_l with this method.

$$P_s = \max\{P_j \mid j = 1,2,..., m\} \tag{4}$$

$$P_l = \max\{P_j \mid j = 1,2,..., m, and j \neq s\} \tag{5}$$

Set double-threshold T_H and T_L, judge rule as

(1)if $P_s < T_L$,then H_0 comes into existence, ESM track don't associate with any radar tracks.

(2) if $P_s \geq T_H$,then H_s comes into existence, ESM track associate with no. s radar track.

(3) if $T_L \leq P_s < T_H$,then need more observation.

The principle of low threshold T_L radiated is to make sure that the leak association of radar and ESM tracks low to primary leak association. In this condition, if H_s comes into true, d_s obey s to distribution of $\chi^2(x, n_j)$, and P_s obeys to distribution of N(0,1). In application, T_L almost is β.

The principle of high threshold T_H radiated is to make sure that the inaccurate association low to primary inaccurate association, if H_s comes into true.

$$T_H = Q_s(t_H) = \int_{t_H}^{\infty} \chi^2(x, n_s)dx \tag{6}$$

And

$$\int_0^{t_H} \chi^2(x; n_s, \delta_s) = \alpha \tag{7}$$

$$\delta_s = \sum_{i=1}^{n_j} \lambda_i^2 = \sum_{i=1}^{n_j} [\frac{v_i}{\sigma}]^2 \quad (8)$$

While v_i is the interval of azimuth.

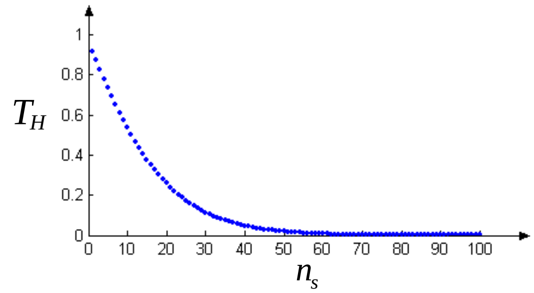

Figure 1. Relation curves of n_s and T_H .

Fuzzy Analysis Method

Assumption that

$$\varepsilon_{ji} = \frac{\theta_e(t_i) - \theta_j^p(t_i)}{\sqrt{\sigma_e^2 + \sigma_j^2}} \quad (9)$$

$$s_{ji} = f(\varepsilon_{ji}) \quad (10)$$

s_{ji} means that the comparability of ESM and radar j tracks . $\forall i = 1,2,...,n_j$,the last of s_{ji} is the comparability vector of comparability, expressed as S_j .

$$S_j = (s_{j1}, s_{j2}, ..., s_{jn_s},)^{/} \quad 1 \le j \le m \quad (11)$$

Assumption that

$$P_j = \exp(-\varepsilon_j) \quad (12)$$

$$\varepsilon_j = \frac{1}{n_j} \sum_{i=1}^{n_j} \varepsilon_{ji}^2 \quad (13)$$

As P_j is humdrum descending function of ε_j , so choose the maximal P_j is equal to choose the minimal ε_j ,and let ε_j be the judge function of radar and ESM track association.

Choose two of the minimal ε_j , find all the judge function ε_j of radar track and ESM track according to formula (12), and then find two of the minimal ε_j , one mark *s*, and the other mark *t*.

$$s = \arg\min\{\varepsilon_j \mid j = 1,2,..., m\} \quad (14)$$

And

$$t = \arg\min\{\varepsilon_j \mid j = 1,2,..., m,\ j \ne s\} \quad (15)$$

Set double-threshold T_H and T_L , judge rule was

(1)if $\varepsilon_s \ge t_H$,then H_0 comes into existence, ESM track don't associate with any radar tracks.

(2) if $\varepsilon_s \le t_L$,then H_s comes into existence, ESM track associate with no. *s* radar track.

(3)if $t_L \le \varepsilon_s \le t_H$,then need more observation.

The principle of affirming high threshold t_H is to make sure that the leak association probability lower than primary leak association probability β when radar and ESM tracks associated. In this condition:

$$P_r(\varepsilon_s \geq t_H \mid H_s) = \beta \tag{16}$$

By calculate, gained:

$$t_H = \chi^2_{n_s,\beta} / n_s \tag{17}$$

If knows β and n_s, we can figure out $\chi^2_{n_s,\beta}$ and t_H.

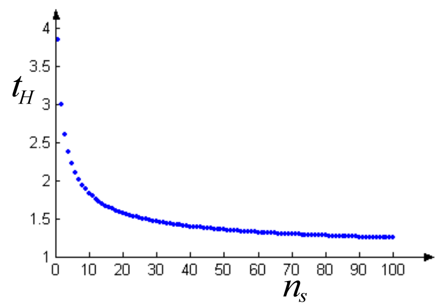

Figure 2. Relation curves of n_s and t_H.

The principle of affirming t_L: suppose the orientation distance (the difference of true orientation) of ESM track and no.*s* radar track is $\lambda\sigma$, when H_s is not come into existence:

$$\overline{H}_s : n_s\varepsilon_s \sim \chi^2(n_s, \delta_s) \tag{18}$$

When $\delta_s = n_s\lambda^2$, we can figure out:

$$P_r\{\varepsilon_s < t_L \mid \overline{H}_s\} = \alpha \tag{19}$$

$$\int_0^{n_s t_L} \chi^2(x; n_s, \delta_s)dx = \alpha \tag{20}$$

α means allow error association probability decided beforehand.

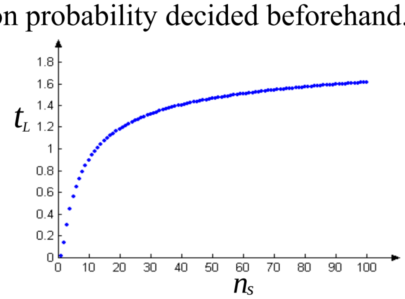

Figure 3. Relation curves of n_s and t_L.

Simulation and Result

Suppose that two vessels combined detection by make use of radar and ESM, the orientation measure error of radar and ESM are $\sigma_j = 0.5^\circ$ and $\sigma_e = 3^\circ$. We assume giving birth to three radar tracks and one ESM track, when the initialization azimuth is 80°, the change rate of the true azimuth is 0.25 degree per second; The initialization azimuth of No.1 radar track is 50 degree, the change rate of the true azimuth is 0.3 degree per second; The initialization azimuth of No.2 radar track is 83 degree and the interval between it and ESM track is $\lambda\sqrt{\sigma_e + \sigma_j}$; The initialization azimuth of No.3 radar track is 90 degree, the change rate of the true azimuth is 0.2 degree per second. In the simulation we take $\lambda = 1$ and analyzed, sampling the azimuth of each track, when the sample interval is 4 second, the sample frequency is less than 100 and the experiment time is less than 400 second, we can obtain each track of the target as showed in Figure 4.

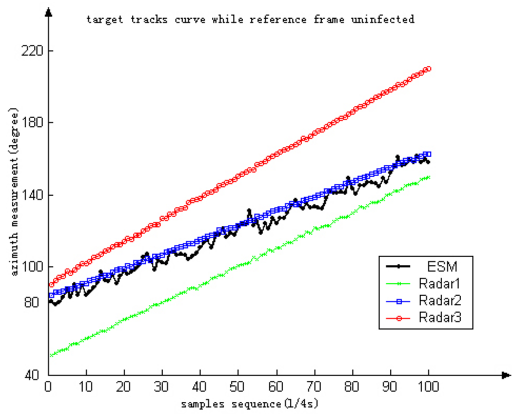

Figure 4. Tracks in uninfected reference frame.

Adopt algorithms include statistical theory and fuzzy colligation analysis to calculate the comparability of track, we can gained the comparability between ESM track and radar track as showed in Figure 5.

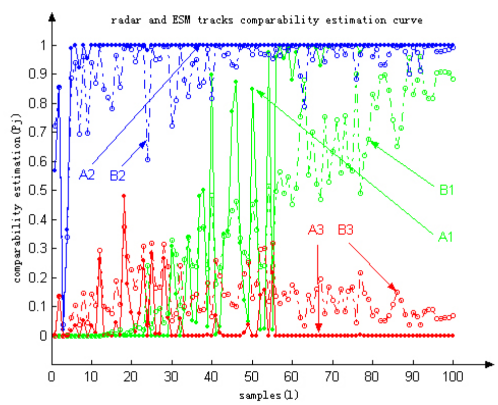

Figure 5. Tracks comparability estimation.

A1, A2 or A3 means the comparability association between ESM track based on statistical theory function and No.1, No.2 or No.3 radar track respectively; B1, B2 or B3 means the comparability association between ESM track based on fuzzy synthetic function and No.1, No.2 or No.3 radar track respectively. We can see from Figure 5 that ESM track and No.2 radar track are associated.

Confirmed the two tracks were associated, then analyze them probability of inaccurate association and probability of leak association when use different sample time l . If α and β are all 0.05, we make Monte Carlo simulation test 100 times, because of $P_l + P_c + P_f$ =1, we can showed them curve respectively in Figure 6, Figure 7 and Figure 8.

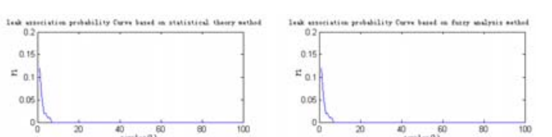

Figure 6. Tracks probability Curve of leak association.

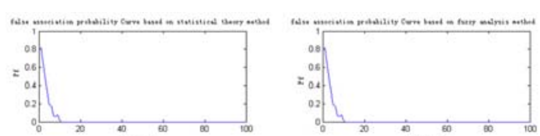

Figure 7. Tracks probability Curve of false association.

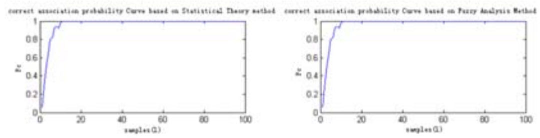

Figure 8. Tracks probability Curve of correct association.

Through simulation analyses, the following conclusions are gained.

(1) The two algorithms are all have upper probability of correct association. When the sampling time is 20, the probability of leak association and probability of inaccurate association which are based on statistical theory and fuzzy colligation analysis inclined to zero, that means the probability of inaccurate association is less than α which gave beforehand, and the probability of leak association always less than β which gave beforehand.

(2) The algorithms of convergence rate based on statistical theory rather than based on fuzzy colligation analysis. The two tracks are associated, we can gained the stability convergence rate when sampling time is about 20 which based on statistical theory, in the same time, the comparability of the two tracks are instability when based on fuzzy analysis, then need more time to make sure that the two tracks are associated. The more sampling time used by the two algorithms, the higher precision the result are.

(3) The comparability of tracks based on fuzzy analysis is more stability. Different sampling time has different comparability of tracks when based on statistical. We first adopt fuzzy judgment principle when the distance of tracks is bigger and the successive change time is longer.

(4) The calculation is easier when adopt fuzzy analysis. The calculation is more difficult when the system have more sensor calibration and conversion or delay error, also the solution of χ^2 is more difficult, in this way were induced slower processing speed based on statistical theory. The solution of χ^2 based on fuzzy analysis is easier.

(5) The simulation above is carried through on the condition of $\lambda = 1$, the conclusion of simulation is the same when λ is 2, 3 or other anomalistic numerical value.

Conclusion

The simulation results in this paper show that both of these two algorithms has high probability of correct association, but the algorithm based on statistical theory has faster convergent speed and litter samples, while the other is simple, and has less calculation. In practice, statistical theory has higher speed and short time, while the tracks azimuth interval is little, the fuzzy analysis result is more precision, while the intervals is better and has less calculation

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