An improved algorithm for multi-factor fuzzy correlation

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Abstract

As a means for Vessel Traffic Service (VTS) to oversee the vessels, the traditional radar and the new navigation method of Automatic Identification System (AIS) are the two sources of getting the vessels' information. Tracks Fusion of the data received from these two sensors becomes the fundamental problem to be resolved in VTS. The tracks correlation is the premise and basis of the tracks fusion. This paper proposed an improved algorithm of multi-factor integrated fuzzy correlation based on the least square-time interpolation. We make generous correlation decision of distance and achieve the targets set in a fixed range, and then after time correction based on the least square-time interpolation we get the correlated tracks set and make fuzzy correlation used the membership function of normal distribution. The simulation experiment shows the proposed fuzzy correlation algorithm is more precise and the data are more close to the actual data of the vessel. The result of this effort can become an efficient method that impacts greatly on the vessel traffic management.

Keywords: Fuzzy Correlation, Tracks Fusion, Automatic Identification System (AIS)

1 Introduction

The VTS (Vessel Traffic Service) is a system of receiving and processing the traffic data, and providing vessels with service. Up to now, many VTS systems have been introduced in world-wide ports. In China, there have been 22 VTS systems covering most of the water area. VTS played an important role in traffic safety, efficiency and environmental protection [1-2]. In VTS, radar is the main tool to monitor and collect data [3]. With the establishment of the shore-based AIS (Automatic Identification System) and inter-fusion with VTS, VTS can get target data such as dynamic, static and navigation information [4-7]. For the VTS' of multiple radars, the cross section data can be collected by nearly radars. When the shore-based AIS is involved in the processing, the track data can be achieved by both radar and AIS [8]. For such a condition, we need a multiple sensors processing data fusion method (MSPDF) [9-12]. MSPDF can fuse the data from different sensors and establish the system tracking, which can increase the tracking performance of VTS.

Some research proposed the method of central clustering used in the tracks correlation. Comparing with the method of focal clustering, in this paper, we propose an improved algorithm multi-factor integrated fuzzy correlation based on the least square-time interpolation method. By experiment, we can conclude that the improved method is more precise and the data are more close to the real navigation data of the ship. Firstly, we get to make a correlation decision of distance from AIS and radar and achieve the correlated targets set [13-15]. And next we go for a multi-factor fuzzy correlation algorithm [16-18]. The fuzzy correlation algorithm design the membership functions of the distance and bearing parameters of the target ships from radar and AIS. Finally, by multi-factor integrated fuzzy correlation we can evaluate the correlation tracks and then make fusion of them. This approach is more effective and accurate especially in the busy water area with high density of ships. To do so, the remainder of this paper is outlined as follows. In the next section, we present the idea of generous correlation of distance and time correction. In Section 3, we have developed an approach to fuzzy correlation based on normal distribution membership function. In Section 4, the fusion method is offered. In section 5, we make the simulation and analyse the result. In Section 6, we close the paper and give some remarks.

2 Decision of distance correlation and time correction

First according to the data characteristic of radar and AIS we should make the distance correlation and time correction.

2.1 DISTANCE CORRELATION

Suppose the position of ship A detected by radar is ($X_{A(t)}$, $Y_{A(t)}$), and the speed is $v_{A(t)}$. Here we suppose ship A is of uniform linear motion. According to the speed at the time we can get the AIS report period T_a of ship A. If the tracks of AIS and radar are correlated at time t, the track of AIS should be within the circle of radius R, shown as in Figure 1.

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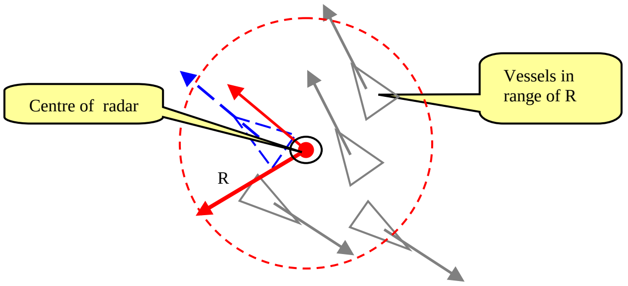

FIGURE 1 Distance correlation

We define R as in Equation (1).

$$R = v_{A(t)}T_a + \delta_r + \delta_a . \quad (1)$$

In Equation (1), δ_r and δ_a are the distance errors of radar and AIS. We correlate the tracks set l of radar with the tracks set l^* detected by AIS. So $S(l)$ is defined as the correlation tracks set of the ship. See Equation (2).

$$S(l) = \{l^* \mid d\left(l(t), l^*(t)\right) \le R\} . \quad (2)$$

In Equation (2), $l(t)$ is the track-point of time t, beginning from 1. And $d(x, y)$ is the distance of x and y.

2.2 TIME CORRECTION BASED ON THE LEAST SQUARE- INTERPOLATION METHOD

Tracks of targets from radar and AIS may be not at the same sample time. So we define a sample time set, and the sample time of all the targets should be corrected by the method of interpolation according to the definition set in order to obtain the position set of them at the same time. The interpolation equation is illustrated in Equation (3).

$$\begin{cases} x_c = v_x \Delta T + x_0 \\ y_c = v_y \Delta T + y_0 \end{cases} . \quad (3)$$

In (3) x_c and y_c are the corrected coordinated value of distance (x, y); v_x and v_y are the speed component of (x, y); ΔT is the time difference of the original sample time; and x_o, y_o are the original distance value of direction (x, y). We select the cubic spline function to make the curve smooth. Suppose $(n+1)$ measurement in the time interval of $[a,b]$ for the targets from radar or AIS, and then divide the time interval of $[a,b]$ into $a \le x_0 \le x_1 \le x_2 \le x_3 \le \cdots \le x_n \le b$. The sample time is x_i $(i = 0,1,2,\cdots,n-1)$. The measurement value of $y_i = f(x_i)$ ($i = 0,1,2,\cdots,n-1$) for each x_i can be the target speed or distance. We can construct the cubic spline interpolation function $S(x)$, satisfying the three conditions as follows.

(1) $S(x_i) = y_i, i = 0,1,2,\cdots,n-1$.

(2) in each $[x_i, x_{i+1}]$ ($i = 0,1,2,\cdots,n-1$), $S(x)$ is a cubic polynomial.

(3) $S(x)$ has the continuous second derivative in $[a,b]$.

According to each measurement value $(x_i, y_i)(i = 0,1,\cdots,n-1)$ we make the $f(x_i) = y_i$ satisfying the Equation (4).

$$\sum_{i=0}^{n} (S^*(x_i) - y_i) = \min . \quad (4)$$

Comparing with the method of central clustering, the data of least square-interpolation method is more close to the actual data of the navigation ship.

3 Multi-factor fuzzy correlation algorithm

3.1 FUZZY FACTORS SET

We take the Euclidean distance of positions and bearings of vessels as the factors of a fuzzy set, as shown in Equation (5) and Equation (6).

$$U = \{u_1, u_2\} , \quad \textbf{(5)}$$

$$\begin{cases} u_1(t) = \left[\left(x_r(t) - x_a(t)\right)^2 + \left(y_r(l) - y_a(t)\right)^2 \right]^{\frac{1}{2}} \\ u_2(t) = \left| \arctan\left[y_r(t)/x_r(t)\right] - \arctan\left[y_a(t)/x_a(t)\right] \right| \end{cases} . \quad (6)$$

$u_1(t)$ and $u_2(t)$ are respectively the differences of Euclidean distance and the bearing at the sample time of t from two targets. $x_r(t)$ and $y_r(t)$ are respectively the position components of (x, y) from radar at the time t. $x_a(t)$ and $y_a(t)$ are respectively the position components of (x, y) from AIS at the time t.

In order to simplify the calculation we set the evaluation set only two conditions as V.

$$V = \{\text{Correlation, Non-correlation}\} . \quad (7)$$

3.2 FUZZY CORRELATION OF SINGLE-FACTOR EVALUATION

We set the single parameter fuzzy array as in Equation (8).

$$R = (r_{kl})_{n \times m} (l = 1, 2) . \quad (8)$$

In Equation (8) r_{kl} means the possibility of the correlation result l of the two tracks considering the parameter k. This is the single parameter correlation membership. r_{k1} is the correlation membership and r_{k2} is the non-correlation membership. We select Normal distribution membership in the algorithm as shown in Equation (9).

$$\begin{cases} r_{k1} = \exp\left\{-\tau_k\left(u_k^{\ 2} / \sigma_k^{\ 2}\right)\right\}, k = 1,2 \\ r_{k2} = 1 - \exp\left\{-\tau_k\left(u_k^{\ 2} / \sigma_k^{\ 2}\right)\right\}, k = 1,2 \end{cases}. \quad (9)$$

In equation (9) τ_k is correction modulus. That is, τ_1 and τ_2 are respectively the correction modulus of position and bearing. $\sigma_k^{\ 2}$ is the variance. $\sigma_1^{\ 2}$ and $\sigma_2^{\ 2}$ are respectively the precision variance of position and bearing.

The fuzzy evaluation array of single-factor is indicated by Equation (10).

$$R = \begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix}. \quad (10)$$

3.3 FUZZY CORRELATION OF MULTI-FACTOR EVALUATION

The weighting fuzzy set is described as in (11).

$$A = (a_1, a_2). \quad (11)$$

Here considering the precision of position is higher than that of bearing we set a_1 as 0.6 and a_2 as 0.4 according to the experience by many experiments.

The fuzzy correlation evaluation of two tracks depends on the weighted fuzzy set *A* and the fuzzy evaluation array of single parameter *R*. So the intenerated fuzzy set is defined as in (12).

$$B = A \bullet R = (b_l) = (b_1, b_2). \quad (12)$$

In Equation (12) b_1 and b_2 are respectively the membership of correlation and non-correlation. We adopted the weighted average method to integrate the fuzzy sets, as showed in Equation (13).

$$\begin{cases} b_1 = a_1 r_{11} + a_2 r_{21} \\ b_2 = a_1 r_{12} + a_2 r_{22} \end{cases}. \quad (13)$$

We define a threshold Td_g to evaluate the membership b_1. When it satisfied with the Equation (14), we take the decision of the correlation.

$$b_1 > Td_g. \quad (14)$$

4 Tracks fusion

4.1 WEIGHTED MODULUS

Here we adopt the statistics weighted estimation algorithm. The data fusion is according to the precision of data from radar and AIS. The higher the precision is, the greater the weight is.

$$\begin{cases} W_{RL} = \dfrac{\sigma_{AL}^{\ 2}}{\sigma_{AL}^{\ 2} + \sigma_{RL}^{\ 2}} \\ W_{AL} = \dfrac{\sigma_{RL}^{\ 2}}{\sigma_{AL}^{\ 2} + \sigma_{RL}^{\ 2}} \end{cases}. \quad (15)$$

In Equation (15), $W_{AL} + W_{RL} = 1$. σ_{RL} and σ_{AL} are respectively the precision of radar and AIS. According to the experience we set σ_{RL} and σ_{AL} as 15 m and 8 m.

4.2 WEIGHTED FUSION

By equation (15) we can get the fusion track *l* in Cartesian coordinates. See Equation (16).

$$\begin{cases} L_x = W_{RL} L_{Rx} + W_{AL} L_{Ax} \\ L_y = W_{RL} L_{Ry} + W_{AL} L_{Ay} \end{cases}. \quad (16)$$

$L_{R(x,y)}$ and $L_{A\,(x,y)}$ are the position values of radar and AIS.

5 Experiment and analysis

5.1 PARAMETERS OF THE TRACKS FROM RADAR AND AIS

We suppose three tracks of targets A, B and C from radar, and one track from AIS.

(1) The speed of ship A in direction (*x*, *y*) are respectively $v_{xA} = 10$, v_{yA} = 0. The track of ship A from radar is shown in Table 1. x_{RA} *and* y_{RA} are respectively the position data of ship A from radar.

TABLE 1 Tracks of ship A from radar

Time series (s)	x_{RA} (m)	y_{RA} (m)
3	80	60
6	120	70
9	130	80
12	200	90
15	170	80
18	200	70
21	210	60
24	230	50
27	20	30
30	290	30
33	330	10
36	370	10
39	410	30
42	460	40
45	500	30
48	520	20
51	590	20
54	590	10
57	620	50
60	620	30

(2) The speed of ship B in direction (*x*, *y*) are respectively $v_{xB} = 10$, v_{yB} =10. The track of ship B from radar is shown in Table 2. x_{RB} *and* y_{RB} are respectively the position data of ship B from radar.

TABLE 2 Tracks of ship B from radar

Time series (s)	x_{RB} (m)	y_{RB} (m)
1	30	60
4	70	30
7	110	50
10	150	100
13	190	100
16	130	170
19	180	220
22	220	180
25	230	290
28	240	310
31	330	350
34	390	350
37	400	360
40	400	380
43	400	430
36	450	470
39	530	520
52	580	560
55	530	590
58	540	630

(3) The speed of ship C in direction (*x*, *y*) are respectively $v_{xC} = 10$, $v_{yC} = 20$. The track of ship C from radar is shown in Table 3. x_{RC} *and* y_{RC} are respectively the position data of ship C from radar.

TABLE 3 Tracks of ship C from radar

Time series (s)	x_{RC} (m)	y_{RC} (m)
2	35	90
5	65	160
8	90	230
11	100	300
14	130	370
17	120	430
20	130	480
23	135	530
26	160	580
29	155	630
32	150	670
35	155	720
38	180	770
41	185	840
44	190	910
47	195	970
50	200	1020
53	215	1070
56	240	1120
59	260	1170

(4) Suppose the sample period of data from AIS is 6 second and the track data is shown in Table 4. A_x *and* A_y are respectively the position data of the ship from AIS.

TABLE 4 Tracks of ship from AIS

Time series (s)	A_x (m)	A_y (m)
2	35	90
5	----	----
8	65	210
11	----	----
14	85	330
17	----	----
20	110	445
23	----	----
26	140	565
29	----	----
32	155	670
35	----	----
38	185	790
41	----	----
44	215	910
47	----	----
50	240	1035
53	----	----
56	270	1155
59	----	----

5.2 FUZZY CORRELATION SIMULATION

Firstly, by the distance correlation we can see the tracks of A and B are out of the threshold, and the track of C is within the threshold, so we continue the fuzzy correlation decision of C with AIS track.

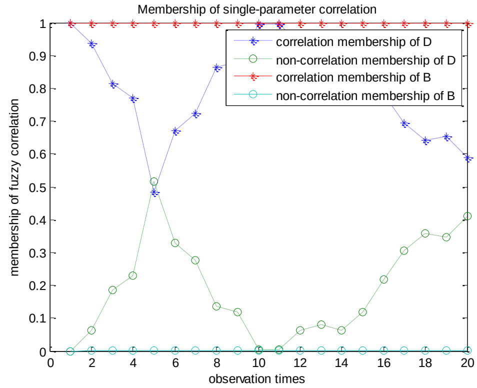

FIGURE 2 Single-factor correlation results

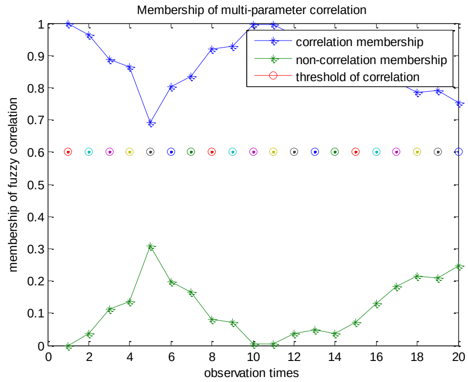

FIGURE 3 Multi-factor correlation results

After the time correction of track C and AIS, we got the correlation membership of a single parameter as showed in Figure 2 and the multi-factor correlation in Figure 3. From Figure 2 the correlation membership of D (distance) is greater than 50% and the correlation membership of B (bearing) is 100%. From Figure 3 fuzzy correlation membership of multi-factor exceeds the threshold of 0.6 as we set. It can be seen obviously that track C is related to the track of AIS.

The fusion track of ship C and the original tracks of A, B is shown in Figure 4. We can see the fusion track is the same as the track of AIS, because the precision of AIS is much higher than that of radar.

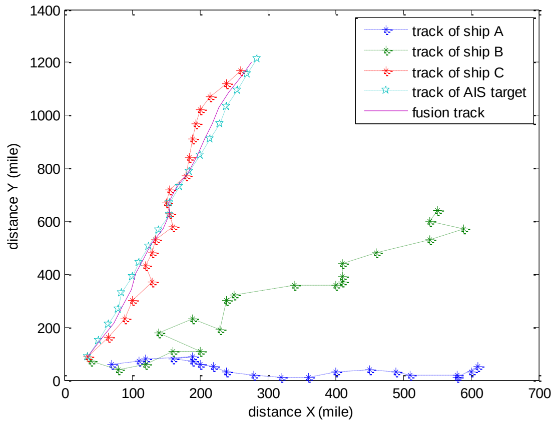

FIGURE 4 Fusion track of C and AIS

We make the experiments for the comparison of the two correlation methods, one is based on the least square-interpolation and the other is the central clustering, the Standard deviation is shown in table 5. From table 5 we can conclude that the correlation algorithm based on the least square- interpolation time corrected is more precise.

TABLE 5 Comparison of standard deviation of the two methods for the time corrected

Method	AIS	radar	fusion
central clustering	1.4308	7.8015	1.5908
least square- interpolation	1.4025	6.9446	1.3091

6 Conclusions

This paper described a fuzzy correlation algorithm to fuse redundant observations to multi-sensor coverage in order to provide an accuracy track of AIS and radar in the Vessel Traffic Service (VTS) and make the navigation safety. The experiment showed that the improved algorithm correctly fuses the redundant sensor observation on the same target and the result is a computationally efficiency and cost effective software solution to a deficiency that impacts greatly on overall waterway safety and protect the ocean environment. The correlation algorithm can be enhanced by adding other attributes such as speed, course, size and track quality to improve the accuracy and reliability of the method.

Acknowledgments

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