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A Multi-source Information Fusion Method for Error AIS Targets Identification

Xinglong Liu[1,2,3], Wei He[*, 4], Xiumin Chu[1,2], Feng Ma[1,2] and Yang Nie[1,2,3]

[1] *Intelligent Transport System Research Center, Wuhan University of Technology, Wuhan, 430063, China*

[2] *National Engineering Research Center for Water Transport Safety, Wuhan University of Technology, Wuhan, 430063, China*

[3] *Energy and Power Engineering School, Wuhan University of Technology, Wuhan, 430063, China*

[4] *Transportation Engineering Institute, Minjiang University, Fuzhou, 350108, China*

Abstract: Automatic Identification System (AIS) is ship navigation equipment. Due to the fact that data-link guarantee mechanism has not been fully resolved, AIS sometimes broadcasts error messages and confused the marine administrators and sailors, so it's important to automatically identify the error messages. In this paper, we proposed an error AIS messages identification framework, which based on prior probability, expert assessment, fuzzy membership degree and Dempster-Shafer's (DS) evidence combining rule. In the framework, ship speed, course and longitude-latitude position are core indexes to evaluate the confidence coefficient of an AIS message. Field experiment is carried out at Wuhan section of the Yangtze River, by field observation, the vessels' real behavior and AIS messages are compared to verify the validity of the algorithm. The experiment results show that for normally sailing ships, the algorithm is able to judge the AIS messages accurately. For ships whose sailing condition changes sharply, such as the touring maritime patrol ship, the algorithm's recognition accuracy is higher than 84.21%.

Keywords: Target identification, dempster-shafer theory, behavior characteristic modeling, information fusion, automatic identification System.

1. INTRODUCTION

AIS is a broadcast communication system applied to marine transportation. It connects the ships and maritime administrators by automatically broadcasting the ships' static and dynamic messages, such as MMSI, speed, course, longitude and latitude, etc.. So, the maritime administrators could supervise the ships by AIS [1]. However, for hardware deficiency and GPS positioning deviation, AIS equipment broadcast error information occasionally, which distracted the administrators and sailors [2]. This problem will bring navigation risk to ships. Therefore, developing an intelligent way to identifying the error AIS targets is quite necessary.

Currently, researches on ship anomaly behavior analyzing are plenty, and most of them are based on AIS data. Steven Mascaro detects the ship's sailing status by Bayesian network [3]. Gerben Klaas Dirk de Vries developed an anomaly behavior recognition method by machine learning, in his research, the ships' track feature was extracted by clustering and classifying the mass historical AIS data in harbor, channel, and anchorage ground [4]. However, these researches didn't concern to the validity of AIS information. Ma Feng [5, 6] constructed two discernment frameworks respectively by DS theory and DSmT, identified the error AIS targets by estimating the ship speed, course and longitude-latitude position, but the estimation depend too much on human experience. Zhang WJ [7] restoring the AIS information by roughly deleting the AIS distortional point, it's practicable for ships sailing normally, but unsuitable for maritime patrol boats and ferries. SANG LZ [8, 9] proposed a AIS track restoring method by interpolation method, it's an arbitrary decision, because the reasoning process is not fully preciseness. Actually, we can never know the precise track for the random error of AIS. So, to develop a reasonable and effective method for error AIS targets identification is necessary.

The error AIS targets appeared randomly. Usually, maritime administrators use their experience to judge the authenticity of AIS targets. They estimate the confidence coefficient of ship speed, course and longitude-latitude separately, and then fuse the confidence coefficient to make the final decision. Referring to the administrators' intelligence, an error AIS targets information fusion identification model based on DS rule was constructed. The contents are arranged as follows. In chapter two, how to acquire the AIS data and how to combine the evidences are described. In chapter three, how to evaluate the evidences' confidence coefficient, that is to say, the method to calculate the Basic Probability Assignment (BPA) for ship speed, course, and longitude-latitude is introduced. In chapter four, the validity of the model proposed above was verified by field experiments. Final chapter is the conclusion.

2. DATA ACQUISITION AND DS COMBINING RULE

2.1. Date Acquisition

To acquire enough data, an AIS base station was set up at Wuhan Yangtze River bridge waterway section (Wuhan waterway). From the AIS base station, over 350000 AIS messages, from April 12, 2014 to May 18, 2014, are stored. In this paper, AIS data from April 12, 2014 to May 12, 2014 are chosen to model the vessels' BPA, and AIS data from May 12,2014 to May 18, 2014 are chosen to validate the model.

2.2. DS Combining Rule

DS combining rule is proposed by Dempster in 1969, and it is the earliest rule to combining multi-source evidence. In DS rule, Dempster extends the events set A to the super power set Θ, which means, in the reasoning process, the events set not only include the events' independent happening probabilities, but also include the intersection set and union set of events. For k independent events, the super power set Θ including 2^k elements. Shafer [10] gave the combining method for evidences, and this method is the standard combining rule of DS theory, it can be shown in formula (1).

$$m(A)=\begin{cases}\dfrac{\sum\limits_{\cap A_i=A}\prod\limits_{1\le i\le N} m_i(A_i)}{1-\sum\limits_{\cap A_i=\phi}\prod\limits_{1\le i\le N} m_i(A_i)} & A\neq\phi \\ 0 & A=\phi\end{cases} \tag{1}$$

Where, m represents the BPA of a piece of evidence, and $m(A)$ is the confidence coefficient of event A.

3. MODELING FOR BPAS

3.1. BPA Model for Ship Speed

Referring to the human experience, ship speed is an important criterion to estimate the authenticity of AIS targets. For a particular waterway section, the ship speed usually is stable, and accord with a certain distribution. So, it's possible to confirm the speed BPA by the ship speed distribution. In this paper, 334926 ship AIS data from April 12, 2014 to May 12, 2014 at Wuhan Yangtze River bridge waterway section(Wuhan waterway) was analyzed, the speed distribution is shown in Fig. (**1**), the X coordinate is ship speed (accuracy is 0.1knot) and the Y coordinate is the frequency.

It can be found that, the ship speed distribution obeys the second-order Gaussian distribution, and there is a peak at speed 3.2~3.3knot. By Matlab curve fitting toolbox, the speed distribution function can be shown in formula (2), and the red line in Fig. (**1**) is the fitting curve for speed distribution.

$$f(v)=a_1\times\exp\left\{-\left[(v-b_1)/c_1\right]^2\right\}+a_2\times\exp\left\{-\left[(v-b_2)/c_2\right]^2\right\} \tag{2}$$

In formula (2), v expresses the ship speed, accuracy is 0.1knot. $f(v)$ presents the frequency. a_i,b_i,c_i ($i=1,2$) are $a_1=8112$, $b_1=3.314$, $c_1=0.7893$, $a_2=3366$, $b_2=5.493$, $c_2=2.863$.

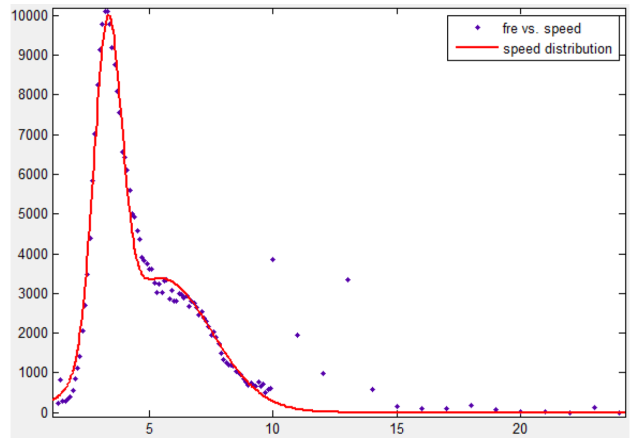

Fig. (1). Ship speed distribution in Wuhan waterway.

Transform formula (2) by normalize process, that means, the area surrounded by fitting curve and coordinates is 1, the transformed formula is shown in formula (3).

$$f'(v)=f(v)/S_{vessel} \tag{3}$$

Where, $f'(v)$ is the processed function, and S_{vessel} equals to 334926.

In Fig. (**1**), the error AIS data is also included in the speed distribution. The error AIS message appeared randomly, so it could assumed that the speed come from error AIS message subject to uniform distribution. To calculating the error rate of error AIS message, 6618 error AIS data from 100 ships at Wuhan waterway is recognize artificially, by evaluating and combining the confidence coefficient of ship speed, angle and longitude-latitude. The result shows that, the error AIS message rate is 27.56%. For any particular speed, the probability of being real AIS message equals to the specific value of normal AIS rate and the sum of error AIS rate and normal AIS rate. It should notes that, the speed is not a continuous distribution, but a discrete value that the unit is 0.1knot. So, the ship speed's BPA function can be calculated by formula (4):

$$m(v)=\frac{f'(v)}{k+f'(v)} \tag{4}$$

Where k is *the* coefficient of error AIS data, it equals to 0.0038, and it is calculated like this: the specific value of error AIS data and normal AIS data divide the ships' general speed scope. The ships' general speed scope is 1.2 knot to 11.2knot, and due to the speed unit is 0.1knot, the general speed scope value is 100 units.

Table 1. BPA of ship course estimated by experts.

	0°	45°	90°	135°	180°	225°	270°	315°
Expert 1#	0.9	0.2	0.7	0.2	0.9	0.2	0.7	0.2
Expert 2#	0.8	0.1	0.6	0.1	0.8	0.1	0.6	0.1
Expert 3#	0.9	0.2	0.6	0.2	0.9	0.2	0.6	0.2

3.2. BPA Model for Ship Course

Compare with ship speed, the ship course related to channel navigation rules, so its confidence coefficient can be estimated based on maritime administrator's experience. For most ships, their course keeps in line with the channel direction. Fewer ships go across the channel lane such as the ferries, and their course almost keep vertical with the channel's direction. In very few cases, the ships' course neither parallels to the channel lane nor orthogonal with the channel lane. The channel direction is shown in Fig. (**2**).

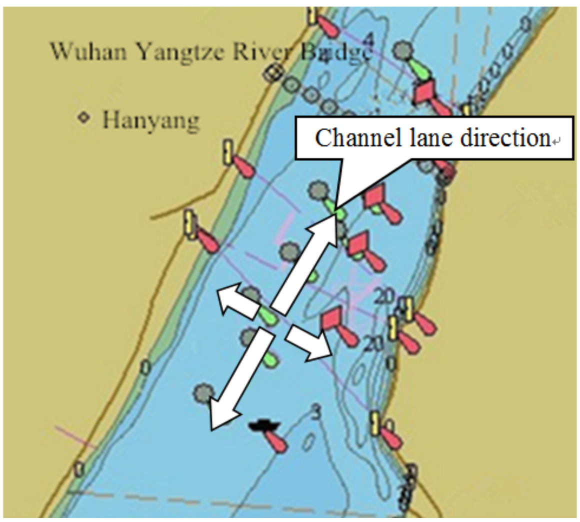

Fig. (2). Channel direction at Wuhan waterway.

Take the intersection angle between ship course and channel lane direction as independent variable, the BPA of ship course is related to the independent variable. Three experts of marine transportation field were investigated, and their suggestion on BPA is shown in Table **1**. The experts only give the particular intersection angles' BPA, such as $0°$, $45°$, $90°$, $135°$, $180°$, $225°$, $270°$ and $315°$. Then, take the mean value as the final BPA. The other angles' BPA can be valued by triangle fuzzy membership, as shown in Fig. (**3**). The BPA function was shown in formula (5).

Where $m(c)$ presents the BPA of ship course, α presents the intersection angle between ship course angle and channel direction, the unit is degree.

3.3. BPA Model for Ship Location

It is certain that, all ships navigate on the water surface, so if the longitude-latitude position from AIS messages located on the land, the AIS data must be error. Generally speaking, most ships sailing in the channel lane, and the nearer to the center of channel lane, the larger number of ships are. At very few cases, for example the patrolling maritime ships or disorientated ships, they sailing out of the lane but absolutely in the water. According to these objective laws, and based on the ships' track distribution in the lane, the BPA of ship longitude-latitude can be obtained by fuzzy membership.

Fig. (3). BPA for the intersection angle.

$$m(c)=\begin{cases} -\dfrac{7}{450}\alpha+\dfrac{13}{15} & \alpha\in[0,45) \\ \dfrac{7}{675}\alpha-\dfrac{3}{10} & \alpha\in[45,90) \\ -\dfrac{7}{675}\alpha+\dfrac{47}{30} & \alpha\in[90,135) \\ \dfrac{7}{450}\alpha-\dfrac{29}{15} & \alpha\in[135,180) \\ -\dfrac{7}{450}\alpha+\dfrac{11}{3} & \alpha\in[180,225) \\ \dfrac{7}{675}\alpha-\dfrac{13}{6} & \alpha\in[225,270) \\ -\dfrac{7}{675}\alpha+\dfrac{103}{30} & \alpha\in[270,315) \\ \dfrac{7}{450}\alpha-\dfrac{71}{15} & \alpha\in[315,360) \end{cases} \tag{5}$$

As shown in Fig. (**4**), the red lines are the ships' track from more than 1000 ships. It can be seen that the track amassed into two ways, the red way on the left is the ships' track going upper stream, and the red way on the right is the ships' track going down stream. This phenomenon is accord with the channel navigation rule at this waterway section, and the track is almost completely coinciding with the channel lane. In this waterway section, the river width is about 1130 meters. For the channel section between K1 and K2 as shown in Fig. (**4**), the ship longitude-latitude BPA is related to its location in channel lane, the nearer to the central lane, the higher BPA is. If the longitude-latitude position locates right in the center of channel lane, the BPA values 1. If the longitude-latitude position locates on the land, the BPA values 0. If the position do not locates in the channel lane but in the river surface, the BPA values 0.1. The BPA function's curve is shown in Fig. (**5**), the X coordinate presents where the ship located in the lane (the value is the distance between ship location and the left river bank, unit is 10 meters), the Y coordinate is the BPA value. The BPA can be calculated by formula 6.

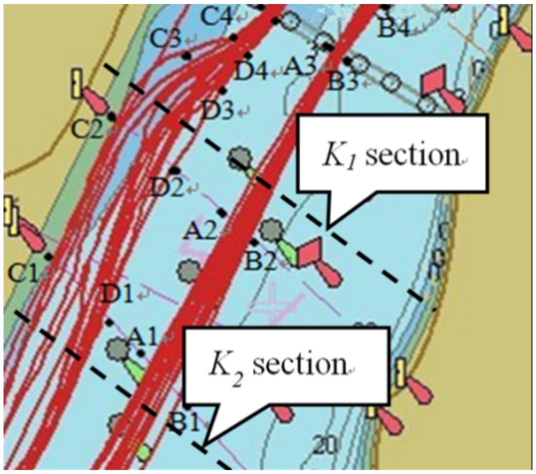

Fig. (4). Distribution of vessels' track.

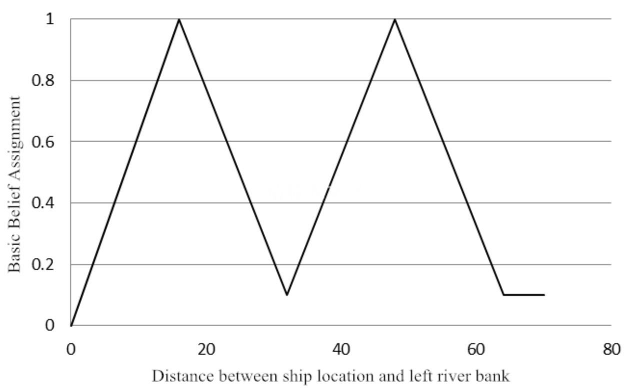

Fig. (5). BPA function for vessel location.

$$m(l)=\begin{cases}\frac{1}{16}d & d\in[0,16]\\ -\frac{9}{160}d+\frac{19}{10} & d\in(16,32]\\ \frac{9}{160}d-\frac{17}{10} & d\in[32,48)\\ -\frac{9}{160}d+\frac{37}{10} & d\in[48,64)\\ 0.1 & d\in[64,113)\end{cases} \quad (6)$$

Where, $m(l)$ is the BPA for ship longitude-latitude location, d presents the distance between ship location and the left river bank, unit 10 meters.

4. EXPERIMENTAL VERTIFICATION

After established the BPA model for ship speed, course and longitude-latitude, the next step is combine the three BPAs to form a final decision.

4.1. Verification Process

Take the AIS targets which crossing K1-K2 section as shown in Fig. (**4**) for example, the AIS targets can be identified in following steps:

First, calculate the BPA of ship speed by formula (4);

Second, calculate the BPA of ship course by formula (5);

Third, calculate the BPA of ship longitude-latitude by formula (6);

Finally, use DS theory to combine the BPAs mentioned above, and gets the final results, as shown in formula (1).

4.2. Experimental Approach and Computational Demonstration

i. Experimental approach

To test and verify the reliability of the AIS target identify algorithm, field experiments are taken in Wuhan waterway from May 12, 2014 to May 18, 2014. As the ships go through the waterway, the AIS base station received and stored the AIS messages broadcasted by ships, at the same time, the ships' behavior was recorded by field observation on the river bridge. Comparing the AIS data and the field observed record, the error AIS data could be find out.

ii. Computational demonstration

Take the AIS data shown in Fig. (**6**) to demonstrate the algorithm proposed in this paper. First of all, display the AIS data on the electronic chart displaying information system (ECDIS). The black spot with a tail presents the AIS data, the location of the spot presents the longitude-latitude, and the tail presents the course angle and speed. The AIS MMSI, angle between ship course and channel direction, ship speed, longitude-latitude is shown in Table **2**.

Table 2. AIS Target Information.

MMSI	Longitude-latitude	Speed (knot)	Angle (degree)
437435680	(114.271605,30.532083)	6.5	10.9

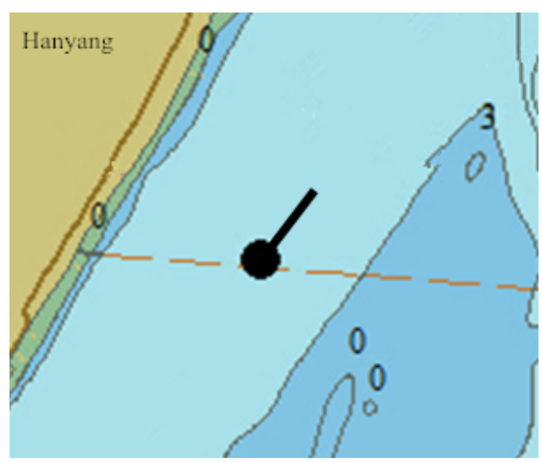

Fig. (6). AIS target display in ECDIS.

Bring the ship speed ($v_{vessel} = 6.6knot$) into formula (4), the BPA of ship speed is 0.69. Similarly, bring intersection angle into formula (5), the BPA of angle is 0.70. By measuring the distance in ECDIS, the distance between ship location and left river bank is 460 meters, bring the distance value into formula (6), the BPA of ship location is 0.42. Then, bring the three BPAs into formula (1) to fuse them, the result is shown in Table **3**.

Table 3. Result of AIS target fusion.

	A	B	$A \cup B$
$m_{speed}(g)$	0.69	0.31	0
$m_{course}(g)$	0.70	0.30	0
$m_{location}(g)$	0.42	0.58	0
$m_{DS}(g)$	0.79	0.21	0

In Table **3**, A presents the evidence "be real target", B presents the evidence "be error target", $A \cup B$ presents the evidence "not sure if it is real target", $m(g)$ presents the BPA, $m_{DS}(g)$ presents the final confidence coefficient calculated by DS. The final result shows that, the confidence coefficient of the AIS target is 0.79, and it's consistent with the actual situation.

4.3. Analysis and Experimental Result

As shown in Fig. (**7**), a 2000t cargo ship passed by the Wuhan waterway section, its MMSI number is 1037435680, the black spots chained with a line is the AIS targets, and they show the track of the ship. The ship is going downstream, and during the experiment, 23 AIS data were collected by the AIS base station. The identification results were shown in Table **4**.

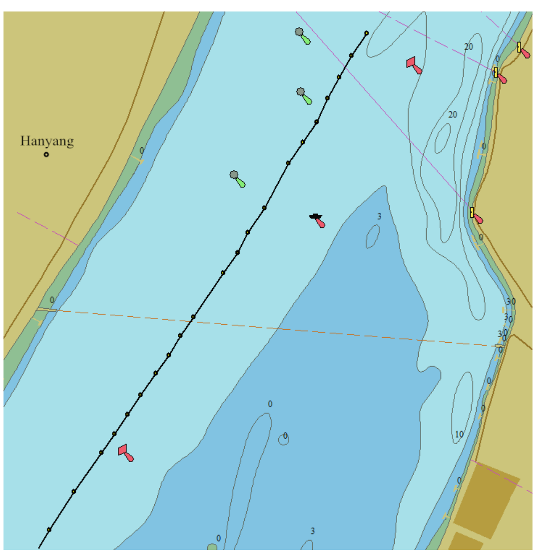

Fig. (7). AIS targets' track for cargo ship going downstream.

It can be seen from the Table **4** that, the combining results for 23 AIS targets are precisely and never mistake the correct targets into error targets.

Fig. (**8**) shows a maritime patrol ship touring at the Wuhan waterway section. The black spots chained with a line displayed its track. The ship turns around at the channel and then going upstream. During experiment, 19 AIS data were collected. The identification results are shown in Table **5**.

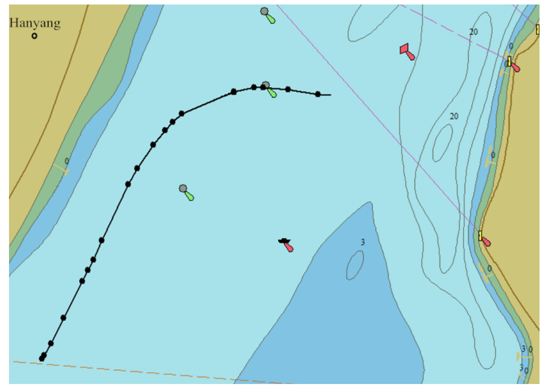

Fig. (8). AIS target's track for maritime patrol.

For the ship is patrolling at this waterway section, its trace feature is much different from other ships. Its speed is higher than cargo ships. As the ship crossing the channel lane, the conflict between BPAs increased significantly. Seen from the Table **5**, it is concluded that, although mistake the real AIS targets to error targets for three times, the algorithm judgment accuracy is about 84.21% overall, still on a high level.

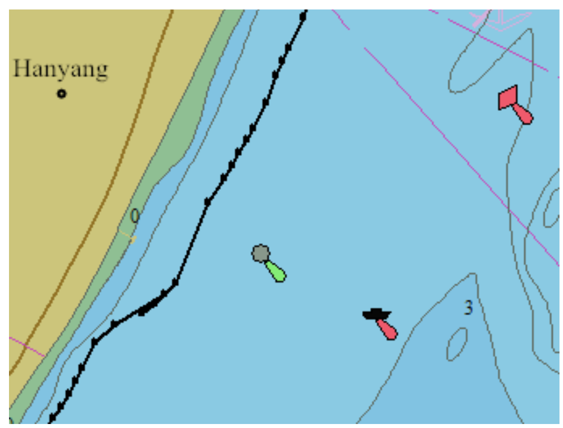

Fig. (9). AIS target's track for cargo ship going upstream.

Fig. (**9**) shows a cargo ship passing by and going upstream at the Wuhan waterway section. During experiment, 22 AIS data were collected. The identification results are shown in Table **6**.

By field observation, the ship keeps going upstream all the time, and scarcely changed its heading. But comparing the AIS targets No.12, 13, 14, 15, it is found that these four AIS targets obviously deviated from the ship's track, what's more, the AIS target No.15 go backwards to the AIS targets No. 13, 14., it's not accord with the real situation, that is to say, these are error AIS targets. The algorithm proposed in this paper successfully identified the error AIS targets No. 12, 13, 14, the judgment accuracy is 75% for error AIS targets, and 95.45% for total.

It could be concluded that, when cargo ships passed by the waterway section, the algorithm never mistake the correct AIS targets to error AIS targets, but on tiny probability mistake error AIS targets to correct targets; when ships patrolling in the waterway and crossed the channel lane, the misjudgment rate increased. But generally speaking, the algorithm could make right judgment on a high level. Referring to the experiments mentioned above, 1330 AIS data from 21 ships are identified. By human recognition, there are 324 error AIS data, proportioned about 24.36%. The algorithm successfully recognized 299 error AIS data, on an accuracy of 92.28%. In consequence, the algorithm proposed in this paper is effective and usable.

Table 4. Basic probability assignment and combining result for cargo ship go downstream.

Targets No.	Speed (knot)	Speed BPA	Angle (degree)	Angle BPA	Distance (meter)	Distance BPA	DS combining result
1	6.2	0.71	4.8	0.79	458	0.88	0.99
2	5.7	0.72	5.6	0.78	454	0.85	0.98
3	5.0	0.72	358.7	0.85	464	0.91	0.99
4	6.4	0.70	0.8	0.85	467	0.93	0.99
5	6.7	0.69	8.5	0.73	470	0.94	0.99
6	7.4	0.63	2.4	0.83	483	0.98	1.00
7	7.4	0.63	9.1	0.73	483	0.98	1.00
8	7.1	0.66	359.7	0.86	490	0.94	0.99
9	6.9	0.67	13.0	0.66	491	0.94	0.98
10	7.1	0.66	351.8	0.74	491	0.94	0.99
11	6.5	0.70	10.9	0.70	493	0.93	0.99
12	6.6	0.69	3.4	0.81	495	0.92	0.99
13	7.4	0.63	10.5	0.70	501	0.88	0.97
14	7.9	0.57	356.6	0.81	503	0.87	0.97
15	6.6	0.69	6.0	0.77	503	0.87	0.98
16	7.4	0.63	14.3	0.64	506	0.85	0.94
17	7.4	0.63	356.4	0.81	508	0.84	0.97
18	7.9	0.57	8.9	0.73	510	0.83	0.95
29	6.8	0.68	359.2	0.85	511	0.83	0.98
20	5.7	0.72	0.1	0.87	513	0.81	0.99
21	6.9	0.67	355.7	0.80	516	0.80	0.97
22	7.2	0.65	9.9	0.71	520	0.78	0.94
23	7.7	0.59	5.3	0.78	524	0.75	0.94

Table 5. Basic probability assignment and combining result for maritime patrol ship.

Targets No.	Speed (knot)	Speed BPA	Angel (degree)	Angle BPA	Distance (meter)	Distance BPA	DS combining result
1	8.9	0.39	244.9	0.37	605	0.30	0.14
2	9.1	0.35	249.5	0.42	519	0.78	0.58

Table **5**. contd…

Targets No.	Speed (knot)	Speed BPA	Angel (degree)	Angle BPA	Distance (meter)	Distance BPA	DS combining result
3	8.5	0.47	242.7	0.35	437	0.76	0.60
4	8.3	0.50	239.2	0.31	409	0.60	0.40
5	7.7	0.59	229.1	0.21	353	0.29	0.14
6	6.5	0.70	204.9	0.48	233	0.59	0.76
7	6.3	0.71	197.7	0.59	215	0.69	0.89
8	6.3	0.71	194.1	0.65	202	0.76	0.94
9	6.3	0.71	188.6	0.73	192	0.82	0.97
10	6.3	0.71	183.1	0.82	183	0.87	0.99
11	6.3	0.71	177.6	0.83	178	0.90	0.99
12	6.7	0.69	174.8	0.79	181	0.88	0.98
13	7.1	0.66	175.2	0.79	180	0.89	0.98
14	7.5	0.62	177.6	0.83	182	0.88	0.98
15	8	0.55	177.8	0.83	181	0.88	0.98
16	9	0.37	176.5	0.81	179	0.89	0.95
17	9.1	0.35	177.1	0.82	178	0.90	0.96
18	9.1	0.35	181.2	0.85	175	0.92	0.97
19	9.1	0.35	182.2	0.83	174	0.92	0.97

Table 6. Basic probability assignment and combining result for cargo ship go upstream.

Targets No.	Speed (knot)	Speed BPA	Angle (degree)	Angle BPA	Distance (meter)	Distance BPA	DS combining result
1	3.3	0.89	167.5	0.67	206	0.74	0.98
2	3.2	0.88	171.2	0.73	210	0.72	0.98
3	3.2	0.88	173.7	0.77	217	0.68	0.98
4	3.1	0.88	177.2	0.82	227	0.62	0.98
5	2.8	0.84	169.5	0.70	234	0.58	0.94
6	2.7	0.82	176.2	0.81	243	0.53	0.96
7	2.6	0.79	178.5	0.84	245	0.52	0.96
8	2.7	0.82	181.1	0.85	243	0.53	0.97
9	2.8	0.84	178.6	0.84	238	0.56	0.97

Table **6**. contd…

Targets No.	Speed (knot)	Speed BPA	Angle (degree)	Angle BPA	Distance (meter)	Distance BPA	DS combining result
10	2.8	0.84	181.4	0.84	228	0.62	0.98
11	2.7	0.82	179.1	0.85	299	0.22	0.88
12	2.6	0.79	200.4	0.55	308	0.17	0.48
13	2.6	0.79	205.7	0.47	298	0.22	0.48
14	2.7	0.82	210.4	0.39	296	0.24	0.48
15	2.7	0.82	196.2	0.61	230	0.61	0.92
16	2.8	0.84	214.3	0.33	226	0.63	0.81
17	2.5	0.76	182.7	0.82	231	0.60	0.96
18	2.7	0.82	173.7	0.77	233	0.60	0.96
19	2.8	0.84	174.2	0.78	232	0.60	0.97
20	2.8	0.84	182.1	0.83	231	0.60	0.97
21	2.9	0.86	183.9	0.81	232	0.60	0.98

CONCLUSION

Based on AIS history data and human experiences, the confidence coefficient of ship speed, course and longitude-latitude from AIS data could be combined by DS rule, so as to make the final decision on whether the AIS data is correct or not. In the field experiments, the proposed algorithm shows good performance. Using this method, the maritime administrator could obtain AIS data with high reliability. However, this algorithm still makes few mistakes occasionally. The reasons can be as follows:

(1) For irregular behavior ships, it is hard to modeling their motion features. Therefore, it is difficult to assign effective BPAs to them;

(2) DS rule has deficiency when the evidences are highly conflict. When ships are crossing the channel lane, conflict between evidences increase significantly, so the DS rule's combining result is not very similar to the real situation.

In further study, if some improvements were proposed to solve the problems mentioned above, the accuracy will be higher, and the algorithm will be more reliable.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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