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ERROR DISTINGUISH OF AIS BASED ON EVIDENCE COMBINATION

[1, 2]FENG MA, [1, 2]XIUMIN CHU, [1, 2]XINPING YAN, [1, 2]CHENGUANG LIU

[1] Intelligent Transportation System Research Center, Wuhan University of Technology

[2] Engineering Research Center of Transportation Safety (Ministry of Education)

ABSTRACT

The Automatic Identification System (AIS) is essential digital communication equipment for maritime safety in inland rivers. The occasional error of GNSS (Global Navigation Satellite System) devices in the AIS equipment will make the terminal send fake dynamic information discontinuously, which needs to be distinguished manually. With the help of the DSmT method, gathering and qualifying the ships motion and lane characteristics, making mathematical models of Dθ discernment frame, it is possible to develop the artificial intelligence. And it is able to discriminate the abnormal messages to improve the reliability of AIS data link. The method has been proved feasible and effective in both simulation environment and field data processing.

Keywords: *DSmT Method, Automatic Identification System, Evidence Combination*

1 INTRODUCTION

The Automatic Identification System, or in short AIS, is a maritime management digital communication data link between vessels and base stations. It is based on the VHF (Very High Frequency) band to broadcast the vessels' dynamic and static information, which would be a great supplement to the traditional radar system. The dynamic information includes the speed over ground, vector over ground, ROT (Rate of Turn), latitude, longitude, heading, which are available in 30 to 50 nautical miles in the open sea, and very useful for the navigation to avoid collision. By now, along with the spreading of AIS, it turns out to be more and more important to the supervisors of inland-rivers and ports, which would be the main resource to estimate the collision risk of specific channels.

The AIS terminal is formed by the VHF model, GNSS model, human-computer interface model, base band model, and power supply model. Along with the development of inland maritime management technology, the Class B AIS devices are spreading in inland rivers. However, because of the limitation of manufactures, the fault of GNSS sensors, and the problems in the installing, the GNSS information in AIS is usually not totally reliable. Meanwhile, the reporting frequency of AIS is restricted to a very low level, so it is common that the AIS tracking is not coincide with the vessels itself. It is a pity that, there is still no method to resolve the problem in the AIS GNSS errors, which will lower the performance of the whole management system based on AIS. Some organizations have pay attention to the research on the reliability of AIS, or the applications of AIS.

With the help of hardware-in-the-loop simulation, it is possible to find the relationship between the PER (Package Error Rate) and AIS signal receiving field strength, and then prove that in specific distance or above, the AIS data link turns out to be unreliable [1-2]. Considering the uncertainty of AIS data link, there is a limitation of the AIS messages in some areas, such as the port, the anchoring berths. And it is also possible that all the AIS network will be overloaded, that no AIS messages can be transmitted [3]. To solve the problem, the AIS terminals may adopt intelligent transmit power to minimize the coverage to protect the AIS data link, based on present AIS targets number and the distance to the base stations [1]. However, the majority of the researches on AIS did not take the reliability into account; they totally believe the AIS track shows how the targets moved. Some researchers adopt the AIS signal as an instance to prove the radar target, and find how to combine them into one object [4]. In the maritime management area, some organizations take the AIS signal as a source to do the statistics on the vessels traffic flow, looking for features about the channels [5]. Other researchers analyze the AIS data to find out the collision risk [6]. According to the assays above, it is known that, the majority of researches did not recognize the errors in

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AIS signals; only the minority has paid attention to the wireless propagation failures.

The error processing in AIS is a typical data fusion problem, which involves choosing information from different sources. By now, the D-S theory is believed to be an efficient tool in this area, which is able to digitalize the empirical data, and set up the combination rules to simulate the artificial judgments. Thus, it might be the most popular way to realize the artificial intelligent. For example, in the robot researches, there will be more than one sensors working together, which can supply different information. And the D-S theory handling seems to be very common [7]. However, the prominent problem of D-S theory is that the conflicts in different evidences may make the whole combination crushed [8].

To solve this problem, some researches proposed some improvements. The DSmT might be the most widely used method to handle the conflicts between evidences. Furthermore, it is very suitable to realize in the computers. In the very beginning, the DSmT is used in the pattern recognitions [9]. Recently, the DSmT is introduced into the AIS data filtering based on the history AIS data [10]. This paper proposes a new improvement for the DSmT application running on the handling of AIS, based on the AIS history data, channel characteristics, vessels movement limitations and other evidences. And the improvement in the simulations and field testing proved to be effective. The second part of this paper introduces the basis of DSmT, the mathematical model, and their application in the AIS; the third part introduces the evidences based on the vessels movement and channel characteristics; the forth and the fifth parts present the simulations and the field testing, to prove the effectiveness of the new method.

2 DSMT MODEL

The DSmT expands the frame of basic discernment θ to the super power set D^θ, which is formed by all the focal elements' intersections and unions. In this way, all the conflicts have been included into the consideration, which is more reasonable and detailed. The combination model of DSmT is listed as below. In the frame of discernment θ, two evidences are A and B, and the focal elements are Ai and Bj, the mass function is therefore m_1 (A_i) and m_2 (B_j), and the rule of combination is,

$$m(X)=\begin{cases}0, X=\varnothing \\ \sum_{A,B\in D^\theta, A_j\cap B_j} m_1(A_i)m_2(B_j), X\neq\varnothing\end{cases} \quad (1)$$

In DSmT, the conflicts have been listed as focal elements, so they can be handled to avoid the influence on the combination, meanwhile; the conflict focal elements are also very easy to be found in this frame. However, the exhaustion of every intersection and union of focal elements will lead to heavy computation, when the number of focal elements in basic θ is 1, 2, 3, or more, the number of focal elements in super set D^θ will be 1, 2, 4, 19, 177580, 7825353, or more. Fortunately, the errors in AIS take place individually, and the focal elements in basic θ are very limited in the normal situations.

The model of DSmT application in the AIS error distinguishes will be shown as below. The most important vessels' dynamic motion attributes include the latitude and longitude, speed over ground and vector over ground. To do the simplification of AIS attributes, it is reasonable to use (X_i, Y_i, SOG_i, VOG_i) to stand for the four attributes of a vessel on time T_i. The model assumes that at the original time T_0, the vessel can be describe as (X_0, Y_0, SOG_0, VOG_0); at T1, the AIgS message reports that the vessel has moved to another position, (X_1, Y_1, SOG_1, VOG_1). The core problem is that at the time T1, the new description (X_1, Y_1, SOG_1, VOG_1) is credible or not. When the new description is not credible, it is reasonable to make the assumption that, the vessel can keep the speed and vector, so the new description will be (X_2, Y_2, SOG_0, VOG_0) at T_1 and to notify the difference, the T_1' is used.

In the manual judgments, the AIS message will be filtered by two factors. One is whether the vessels movement will follow the regular pattern or not; the other is whether the vessel is running on the normal channel. To simulate the artificial judgments, it is rational to quantize the two evidences to Emotion and Elane. The two evidences may cause different mass functions.

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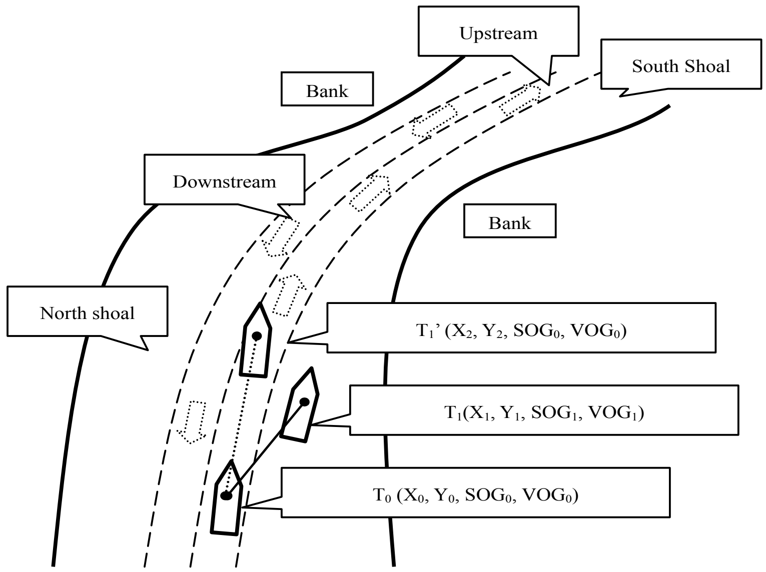

Figure 1: Typical DSmT Judgment on AIS

3 EVIDENCES COMBINATION

3.1 A VESSEL MOTION EVIDENCE

It is normal to judge whether the new motion description is credible or not based on the motion regular pattern. Along with the increasing of vessel's size, the force of inertia will increase too; the course-changing and speed-changing will be harder. Fortunately, the AIS message contains enough information to indicate the tonnage, dimensions and types. It is easy to know the motion attributes of different vessels. Based on the motion attributes, new descriptions of vessel will acquire qualification judgments. The processing will use the acceleration and rate of turn as the main basis.

1) Acceleration

$$A = \frac{|SOG_1 - SOG_0|}{T} \quad (2)$$

The acceleration of vessel will be decided by the running state of the vessels. And different situations will cause different accelerations, which include:

(i) Normal sailing, $0 \leqslant a \leqslant A_1$, the most reasonable value, set as P_1;

(ii) Unusual sailing, $A_1 \leqslant a \leqslant A_2$ the collision or GNSS devises error, set as P_2;

(iii) Acceleration out of the normal range, $A_2 \leqslant a \leqslant A_3$ vessels backward or GNSS devises error, set as P_3;

(iv)Acceleration out of the possible range, $A > A_3$, the confidence is close to 0.

Where, the $A_2 > A_1$, $P_1 > P_2 > P_3$, the P_1, P_2, P_3 are variables. As the A increases, they will decrease rapidly.

The confidence of A will follow the pattern in Figure 2.

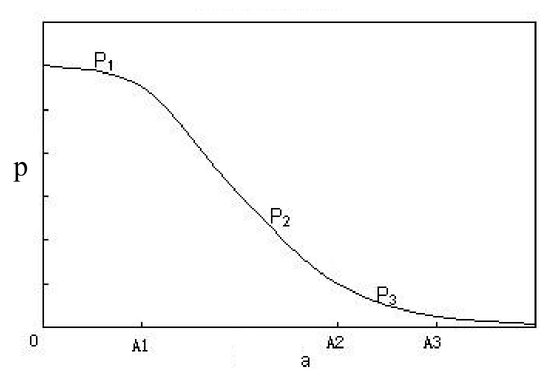

Figure 2: Confidence And The A

2) Rate of turn

The steering engines of vessels have their limitation, which is about 35 degree. So in a specific time, there is a limitation in the vessel course changing. In the field running, the course changing will also get influenced by the flow of rivers. If at time A, the vessel is running on the course 0, the next time B, the rate of turn CB,

$$C_B = \frac{|VOG_1 - VOG_0|}{T} \quad (3)$$

When the direction of flow is vertical with the course of the vessel, the rudder angle will be the max value, the rate of turn reach the maximum CM. According to the experiences, the vessels are most

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likely to keep the course. Meanwhile, the situation where the rate of turn is larger than the CM is very rare, which might be the collision. So the CB can be shown in Figure 3.

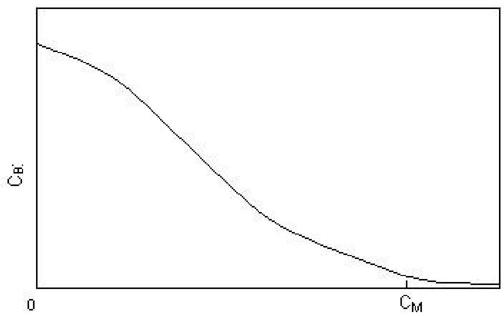

Figure 3: C_B And The Confidence

The P and C_B stand for the confidence on the accelerations and rate of turn, so the products will give the qualification specification for the confidence of the new description of vessel. According to other researches, the P and C_B will be monotone decrease. Due to the complexity of different vessels, especially on the tonnages and actuating units, it is necessary to build up a database to store all the relationships between confidences and different motions. In this paper, to simplify the model, all the calculation will set all the key parameters manually, and assume that the changing pattern among different parameters follow the linear variation.

3.2 CHANNEL CHARACTERISTICS EVIDENCE

The inland-river sailing vessels will follow the shipping lane except in case of an emergency or devices faults. So the AIS messages reporting the vessels are violating away from the shipping lane are usually considered to be not genuine. By this means, the shipping lane or the GIS information is the other important evidence to make judgments on AIS messages. In fact, the vessel will obey the shipping lane rules sometimes, such as crossing through the lane and berthing, which will lead to different motion track. To avoid the situation above imposing influence on the combination processing, it is necessary to estimate the running status of each vessel. One possible way is that, in a period T', only the vessel is running parallel to the shipping-lane, can the model assume it as running along with the shipping-lane, and the channel evidence will be available.

In Figure 4, the position confidence will be classified to 3 groups, in the lane, out of the lane, and on the land, different position will lead different confidence value. The confidence in the lane will reach the maximum; out of the lane, the confidence will decrease, along with the approaching to the shoals and banks; on the land, the confidence is 0; the vessel is running to the other side of the lane, which is against the regulations, the confidence is smaller than the normal one, but larger than the position out of the lanes. Based on the rules above, it is possible to quantify all the positions confidences as in the Figure 4.

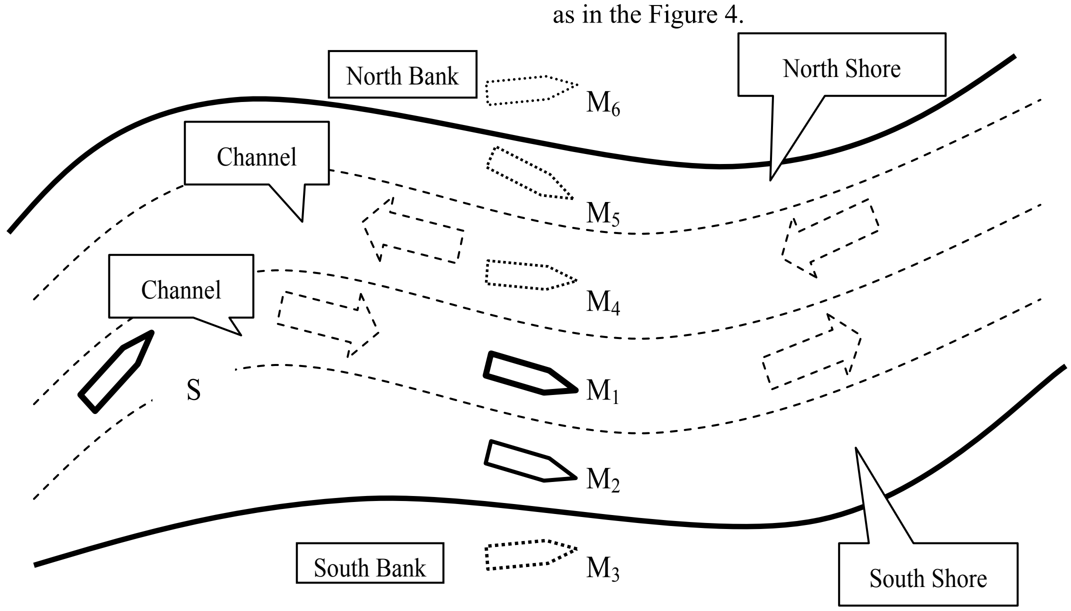

Figure 4: Evidences Qualification In Channel Distribution

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In the Figure 4, the vessels is running from the original position S, and the next possible positions are the M1 to M6, the confidence value will be M1>M2>M4>M5>M3=M6=0∞, standing for the in lane running, out of lane running, out of lane shoal running, out of lane error direction running, out of lane error direction shoal running, south bank running, north bank running respectively. To simplify the model, the combination assumes that the changing pattern among different values is a linear variation.

3.3 Evidences Combination Model

There are two possible values in the vessel running. 1) Just follow the report of AIS message, θ_1; 2) assume that it will follow the forward speed and course, θ_2.

According to the rule of DSmT, the origin discernment frame will be $\Theta = \{\theta_1, \theta_2\}$, the focal elements are independent from each other. The Emotion and Elane stand for the evidences from the vessel motion and channel characteristics respectively. The probability distribution functions will be $m_{motion}(\theta_1)$, $m_{motion}(\theta_2)$, $m_{motion}(\theta 1 \cup \theta_2)$, $m_{motion}(\theta_1 \cap \theta_2)$; $m_{lane}(\theta_1)$, $m_{lane}(\theta_2)$, $m_{lane}(\theta_1 \cup \theta_2)$, $m_{lane}(\theta_1 \cap \theta_2)$.

Where,

1) θ_1, trust the AIS messages;
2) θ_2, trust that the vessel would keep the speed and vector.
3) $\theta_1 \cup \theta_2$, do not sure trust AIS messages or original status;
4) $\theta_1 \cap \theta_2$, empty set, unavailable.

The flow chart of combination will be shown in Figure 5.

Obtain the AIS message; estimate whether the vessel is running in the shipping lane or not; if so, fetching the motion evidences and channel evidences and the confidences value based on the look-up tables, make the combination with DSmT rules.

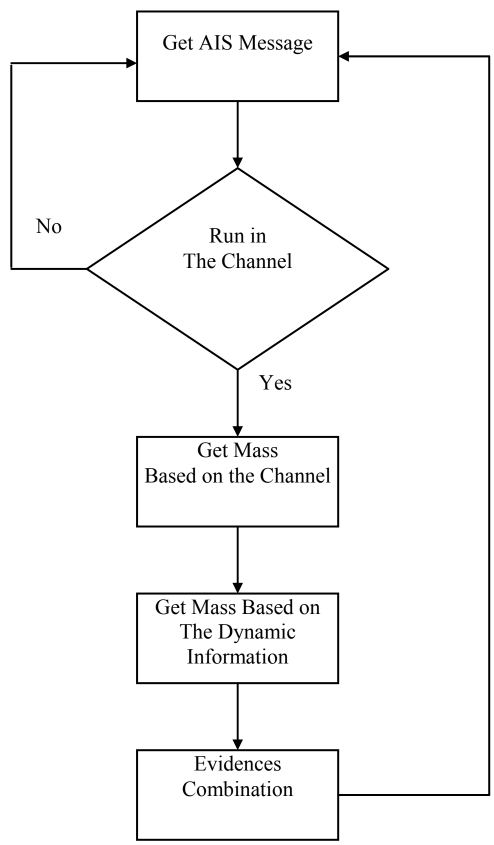

Figure 5: Combination Flow Chart

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4 EXPERIMENTS

4.1 SIMULATION

To prove the models above, the paper proposes the simulations as below.

First comes to the simulation platform. The simulation will be built on the S57/S52 GIS engine, which includes all the layers in the ENC and an additional layer to describe the confidence value in different positions based on the empirical data and channel distributions.

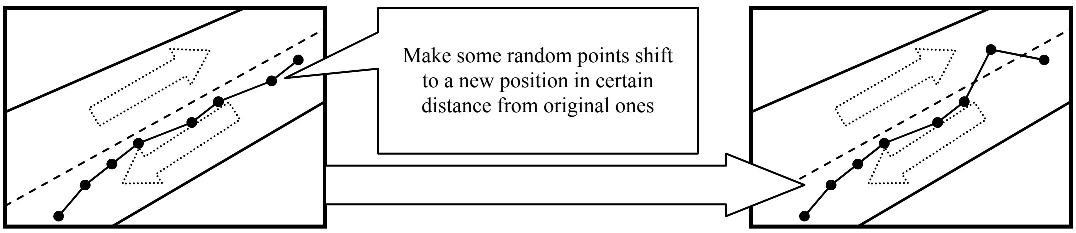
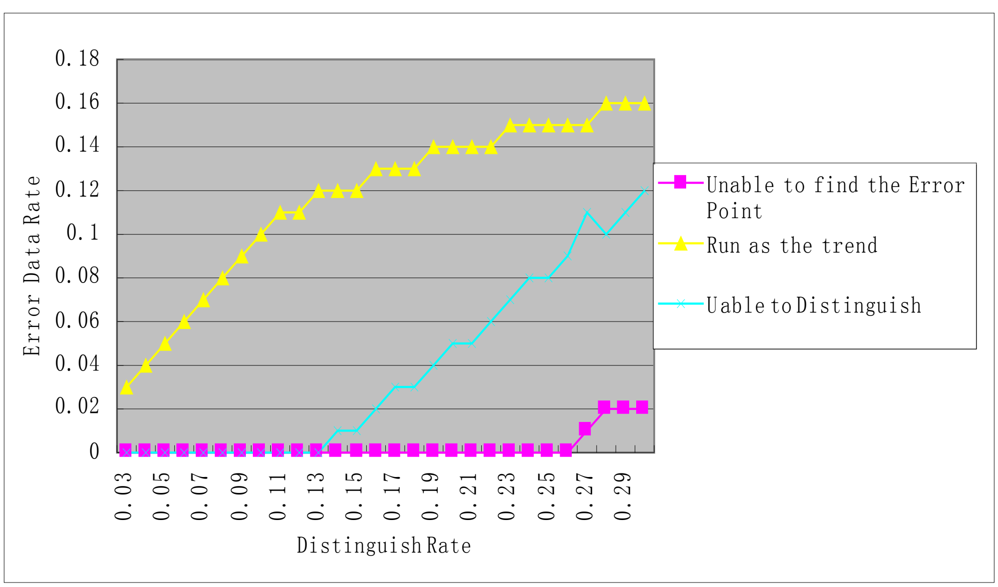


Figure 6: the Simulation Random Deviation

Next is the simulation processing. Set different vessel to run in the platform, with random errors points to simulate the paths error in AIS messages.

1) Set an original vessel running track as Figure 6 in the left.
2) Fetch random errors into the original track; make the GNSS value jump to another point in random as Figure 6 in the right. The deviation will be set as 10 to 100 meters. In large samples experiments, the distribution of deviation points will follow the Poisson distribution to original points which are close to the filed GNSS devices faults.
3) Adopt two evidences to judge each position, get confidence value individually. Set the parameters' value. The vessel whose heading is near to be parallel to the shipping lane, less than 25 degree will be considered as running along the lane, the key parameters will be set as, A_1=3.0,A_2=5.0,A_3=10.0, C_M=10.0. To the channel evidence, the P1=0.8, P2=0.1, P3=0.01. The channel evidence, M1=0.5, M2=0.3, M3=M6=0.0001, M4=0.1, M5=0.01.
4) Use DSmT to solve the super set D^θ.
5) Output the result. The simulation use 1000 as a group, set 1% to 30% error rate, and running the DSmT in 30 times, the result is shown in Table 1,

Table I: Simulation Result



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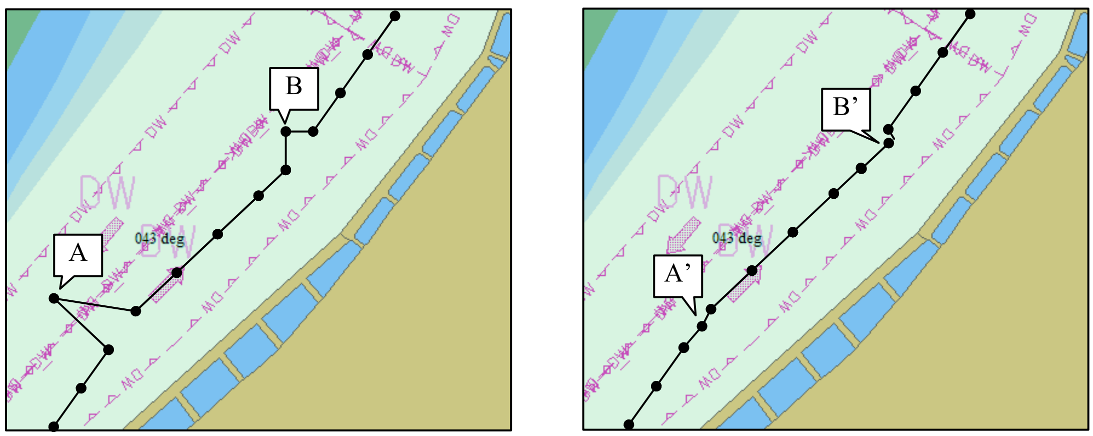
In the Table I, the horizontal coordinates stand for the error rate in the testing group, the vertical coordinates stand for the distributions of the results of the DSmT processing, which includes the following three cases: 1) do not trust the AIS message and, believe the AIS target is running with the same speed and vector; 2) do not sure whether to trust the AIS message or the original status; 3) judgments errors.

In the simulations, the DSmT is able to distinguish the error messages immediately; even the error rate has risen to as high a level as 13%, it can also give an ‘uncertain’ report, when the error rate has risen to 27%, the judgments error start to appear. As has been proved, the DSmT is totally efficient in AIS message simulation handling.

4.2 Field Testing

The simulation proves the effectiveness in the AIS errors distinguish when the AIS message contains motion or channel position errors. In the field running, the errors in the AIS messages will be much complex and diversified, which will expand the method into the field data processing to prove the practical applicability. The field data was gathered from 8.2.2012 to 22.2.2012 at the Baishazhou in Wuhan Changjiang Channel. There are 635233 AIS messages. The DSmT picked up 12112 error messages on 1.3% of vessels, accounting for 1.9% of the total. The typical error vessel is shown in Figure 7. The ENC is in the S57/S52 form, including banks, berth areas, lanes, and shoals. Similar to the simulation, the confidence values layer is added too.



(i) Original Data *(ii) After Processing*

Figure 7: DSmT Processing in Field AIS Data

In the Figure 7 (i), the dot stands for the AIS messages reporting positions, in accordance with experiences, the fault points will be A and B. With the help of DSmT processing, in Figure 7 (ii), the A and B are captured directly, and fix the track with the original speed and vector, which is much more close to the real track of vessel. Similarly, the method has captured 47 fault points in this vessel in 55 minutes. The field testing has proved that the DSmT with channel and motion evidences will be very suitable for distinguishing AIS messages.

5 CONCLUSIONS

Recently, the inland rivers traffic flow has increased a lot. The vessels are running in long and narrow shipping lanes. So the fault of GNSS devices will cause message error in AIS, which can do a great harm to the administration and collision avoiding. The error can be picked up manually, but obviously this will lower the efficiency of navigation and supervision. Summarizing the experience of artificial works, we can easy know that the motion and channel characteristics are chief evidences to judge AIS messages. With the help of DSmT, it is possible to do the combination of the evidences above. In the simulation and field testing, the method has been proved efficient. The conclusions are listed as below,

1) In the simulations, DSmT is able to distinguish error correctly on condition of an error rate no more than 27% ;
2) In the field testing, the DSmT shows a similar ability to distinguish the error messages.

In this paper, to simplify the models, all the parameters are set to ideal values; it is, however, quite different in field running. In the next step of the

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research, it is required to set up a new model to fetch the parameters for different vessels. Besides, the distinguishing method in this paper merely involves the motion information. But in reality, the errors about static information, such as the name, the MMSI, the dimensions errors are more common. Therefore, the method to correct such static errors is much more urgent.

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