2017 4th International Conference on Transportation Information and Safety (ICTIS), August 8-10, 2017, Banff, Canada

Enhance the AIS data availability by screening and interpolation

Daiyong Zhang
School of Logistic Engineering,
Wuhan University of Technology;
National Engineering Research Center for Water Transport Safety, Wuhan University of Technology;
Fujian Provincial Key Laboratory of Information Processing and Intelligent Control (Minjiang University)
Wuhan, Hubei 430063, China
zh_young@whut.edu.cn

Qing Wu
School of Logistic Engineering,
Wuhan University of Technology;
National Engineering Research Center for Water Transport Safety, Wuhan University of Technology;
Wuhan, Hubei 430063, China
wq@whut.edu.cn

Xiumin Chu
National Engineering Research Center for Water Transport Safety, Wuhan University of Technology;
Wuhan, Hubei 430063, China
chuxm@whut.edu.cn

Jia Li
Information Center,
Changjiang Maritime Safety Administration;
School of Energy and Power Engineering,
Wuhan University of Technology;
Wuhan, Hubei 430063, China
124725515@qq.com

Xinglong Liu
National Engineering Research Center for Water Transport Safety, Wuhan University of Technology;
Department of Physics and Electronic Information Engineering,
Minjiang University;
Wuhan, Hubei 430063, China
liuxinglong_its@163.com

Wei He
School of Economics and Management,
Minjiang University;
Fuzhou, Fujian 350108, China

***Abstract*—The AIS broadcasts the ship's navigation data automatically and autonomously through VHF band. It plays an important role in collision avoidance and maritime situational awareness. However, in inland waterways, it is common that the AIS data-link was obstructed by the river bank and mountains, or sometimes the AIS was encountered with the electromagnetic interference. Consequently, the AIS dynamic data is often lost and mixed with inaccurate, which may lead to misjudgment of the traffic situation. To address this problem, a method was proposed to enhance the availability of AIS data in this paper. Firstly, according to the ships' maneuverability, a set of factors, such as the moving distance, speed, acceleration, and course change rate, were designed to screen the inaccurate AIS data. Then, the piecewise cubic Hermite interpolation and cubic spline interpolation were employed to restore the AIS data. A real AIS trajectory was introduced to validate the accuracy of the two interpolation methods, which proves that the cubic spline interpolation performance is better than piecewise cubic Hermite interpolation. Field experiments in Wuhan reach of Yangtze River show that the method proposed in this paper is highly effective. The accuracy of the location is 3.5m, the speed accuracy is 0.05m/s, and the course accuracy is up to 0.7 degrees, the AIS data can be accurately repaired.**

Keywords*—*AIS; data availability; ship maneuverability; cubic spline interpolation; trajectory restoration

I. INTRODUCTION

Due to the advantages of large transportation volume, low cost, low energy consumption and less pollution, waterway transportation plays an important role in the comprehensive transportation system in China. Researches on informationization and intelligent system of shipping management have always been the concern of the international shipping industry, and getting real-time traffic information is the key to build the intelligent shipping system [1].

Automatic Identification System (AIS) is composed of shore station and ship station. The ship station exploits the GPS module to obtain the dynamic information of vessels, such as position (presented by longitude and latitude), speed over ground, course over ground, etc. Meanwhile, the pilot input the static information, such as the MMSI, call sign, gross tonnage, draft and dimension, etc. into the ship station with keyboard. Then, the ship station modulates the dynamic information and static information into AIS messages and conveys the AIS messages to other ship stations around. According to the IMO regulations, the ship station usually sends dynamic AIS messages every 6 to 30 seconds when the ship is normal voyage [2-5]. The shore station receives and decodes the AIS message transmitted by the ship station, and then displays the information of the ships on VTS screen. Therefore, the AIS enables the exchange of ship information among vessels and maritime administrators. It is helpful for maritime regulation and ship collision avoidance.

AIS is an important means to collect ship traffic information at present. AIS messages contain large volumes of information, thus the AIS is an important data source for analyzing the motion pattern and navigational risk of vessels. However, the AIS utilize the VHF band communication, which makes the data-link of AIS not reliable. Consequently, the raw AIS data is not fully available, i.e. the AIS data is not completely correct and integrated [6,7]. The incorrect and lost AIS data will interfere with maritime regulation, leading to misjudgment of the maritime situation awareness. Meanwhile, it will decrease the effectiveness of analysis on ship motion pattern and traffic flow, which is based on the AIS data. Therefore, it is necessary to study the correctness and integrity of AIS data, and identify the inaccurate AIS data and restore the lost AIS data.

Ma et al. [8,9] conducted studies on the availability of AIS information, and proposed approaches for identifying the inaccurate AIS data based on the DS evidence theory and improved DSmT theory [10,11], however the construction of evidence in the proposed methods lack strict reasoning process. In order to improve the effectiveness of the evidence, Liu et al. [12,13] gave an likelihood based method to construct the evidence by statistical analysis on effective prior data samples, and proposed ER rule and the PCR6 rule based methods to identify the inaccurate AIS data. The evidence based methods can give an accurate identification on AIS data, however the methods seems inefficient, because too many effective data samples should be collected before application. Interpolation methods are popular in restoring the time series. Liu et al. [14] employed the three spline interpolation method to restore the coordinate of lost AIS data. Nguyen [15] utilized piecewise cubic Hermite interpolation to restore the trajectory of vessels. However, these researches are competent only if the lost AIS data are not consecutive, and the restoration of speed and course are not in consideration. Liu et al. [16] introduced the random algorithm into AIS position restoration, but the randomness of the position is not strong enough to fit the actual AIS data.

In this paper, we summarized the categories of inaccurate AIS data firstly, and proposed a method to screen the inaccurate AIS data. Then, a comparative study was conducted to validate the accuracy of improved cubic spline interpolation method and piecewise cubic Hermite interpolation. Experiments show that the method proposed in this paper can correctly screen the inaccurate AIS data and restore the lost data effectively.

II. METHOD FOR SCREENING DATA

In order to capture the real time AIS data, an AIS shore station was set up (base station model is SAAB R40) in the Wuhan section of the Yangtze River. The shore station can receive the AIS data from vessels 10 kilometers around. Raw AIS data was collected in October 2016, to validate the proposed method. According to the raw AIS data, the categories of inaccurate AIS data are summarized as follows: unreasonable stop during moving forward, impossible high speed, drift track point, unreasonable acceleration and rate of turn. It is necessary to screen the raw AIS data to get the correct data. In this paper, we designed five rules to screen the inaccurate data according to the ship's maneuverability, as shown in follows:

A. *Unreasonalbe stop in moving*

The adjacent AIS data is exactly the same sometimes as the vessel is moving ahead. For this type of inaccurate data, the cleaning rules are as follows. If the speed of the *i-th* point is higher than 2 knots, but the coordinate, speed, and course are the same as the *i*-1*th* point, the *i-th* data should be deleted. As shown in equation (1):

$$\begin{aligned} & v=\sqrt{(v_{lon}^{i})^2+(v_{lat}^{i})^2}>2 \\ & |lon_i-lon_{i-1}|=0 \\ & |\mathrm{lat}_i-lat_{i-1}|=0 \qquad\qquad i=2,3,...,\mathrm{m}-1,m \\ & |v_{lon}^{i}-v_{lon}^{i\text{-}1}|=0 \\ & |v_{lat}^{i}-v_{lat}^{i\text{-}1}|=0 \end{aligned} \tag{1}$$

B. *Impossible high speed*

Due to the limitation of power engine and navigational rules, the speed of vessels in inland river is less than 16 knot. Thus, the correct speed range of AIS data is 0~16 knots, as shown in equation (2):

$$v_i=\sqrt{(v_{lon}^{i})^2+(v_{lat}^{i})^2}>16 \quad i=2,3,...,\mathrm{m}-1,m \tag{2}$$

Any AIS data complies with the formula (2) should be deleted.

C. *Drift track point*

When the track point is drift away, the distance between the drift point and the adjacent track points will increase. Consequently, the average speed will increase as well. If the average speed exceeds the maximum speed of the ship, the track point will be considered to be the erroneous data. As shown in equation (3):

$$\bar{\upsilon}_i=\sqrt{(k_1(x_i-x_{i-1}))^2+(k_1(\mathrm{y}_i-y_{i-1}))^2}>16 \tag{3}$$

Where k_i(i=1,2) is the factor for transferring coordinate to distance, and k_1 = 96297.6, k_2 = 111194.9 near latitude 30°N. Any track point that complies with equation (3) should be deleted.

D. *Unreasonable acceleration*

According to the design specifications of inland ships, the distance for a ship to accelerate from zero to the design speed is 20 times longer than the length of the ship. When the ship is empty, the distance reduced to 1/2~2/3 times of the original distance. To obtain the maximum acceleration, the minimum distance values to 10 times of the length of ship. Assuming that the length of the ship is L, the design speed is V_m, the time from the static accelerate to the design speed is t_m. The travelling distance of the ship can be obtained by formula (4) and shown in *Fig.1*. The maximum acceleration of the ship can be known from formula (5) according to the distance divides velocity transformation formula.

978-1-5386-0437-3/17/$31.00©2017 IEEE

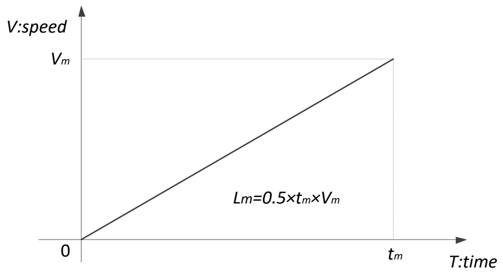

Fig.1 diagram for computing the maximum distance and acceleration

$$L_m = 10 \times L = 0.5 \times t_m \times V_m \tag{4}$$

$$a_{\max} = \frac{V_m}{t_m} = \frac{V_m^2}{20 \times m} \tag{5}$$

Usually, the ship's maximum speed is 16 knot, so the V_m is about 8.23 m/s. The length of the ship can be queried from the AIS static data. For a ship with a length of 110m, the maximum acceleration is 0.03m/s^2. It can be seen that the maximum acceleration of any cargo ship can be calculated by (4), (5), any data beyond the maximum acceleration range should be deleted.

E. Unreasonable rate of turn

According to the design specification of inland river ships, the maximum diameter of a ship can be obtained by the formula $D = k \times L$, in which k is the coefficient to measure the ship maneuverability, usually for the inland river ship, the range of k is in 2~4. The maximum swing diameter represents the maximum variation rate of the ship track. As shown in *Fig. 2*, when the ship is in constant motion, its path is in the direction of the tangent of the trajectory. Assume that ships move from D_0 to D_1, the corresponding time were t_0 and t_1, the speed v unchanged, the arc angle is w, the maximum rate of turn d_{wmax} can be derived by equation (6), (7) and (8).

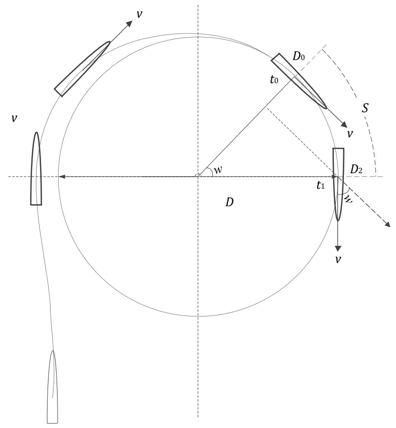

Fig. 2. Schematic diagram of the maximum rate of turn for a ship entering a constant cycle

$$D = k \times L, k \in [2,4] \tag{6}$$

$$\Delta t = t_1 - t_0 = \left(\frac{w\pi D}{360}\right) \Big/ v \tag{7}$$

$$d_{w\max} = \frac{w}{\Delta t} = \frac{360v}{k\pi L} \tag{8}$$

Where w is the steering angle of the ship, the unit is degree; L is the length of the ship, the unit is meter; t represents the time, the unit is seconds; v is the ship speed, unit: m/s. For example, the length of 110 meters for the ship speed of 8knot, the maximum turning rate is 2.1437°/s, where the minimum value of k is 2.

After getting rid of the wrong AIS data, we can get the correct AIS sequence. However, the original AIS data will be partly missing, which needs to be repaired to get a complete and correct data. According to the AIS protocol, the time interval of class-A ship station does not exceed 10s, the time interval of class-B ship station does not exceed 30s. In the progress of repairing AIS data, we need to interpolate the data according to the time interval, the maximum time interval of 10s and 30s.

III. METHOD FOR DATA RESTORATION

After data cleaning, we can obtain the accurate AIS data series. For better interpolation, the time, longitude, latitude, velocity and course in the AIS data are selected for pre-processing, and the raw data is sorted according to the time. The latitude and longitude of the starting track point are treated as the origin of coordinates. Calculate the time difference, speed vector along longitude direction, speed vector along latitude direction between the adjacent AIS data. Setting t_i as time, lon_i as longitude, lat_i as latitude,v_i as speed,θ_i as course angle,$v_{loni} = v_i * cos\theta_i$ is speed vector along longitude, and $v_{lati} = v_i * sin\theta_i$ is speed vector along latitude.

A. Piecewise cubic Hermite interpolation

Suppose there are n track points in the track sequence. The Hermite interpolation interval of longitude for time section $(\mathrm{t}_i, \mathrm{t}_{i+1})$ is as follows:

$$lon(\mathrm{t_i}) = \mathrm{a_i t}_i^3 + \mathrm{b_i t}_i^2 + c_i t_i + d_i \tag{9}$$

On the type derivation function on the rate of time,

$$v_{loni} = \frac{dlon(\mathrm{t_i})}{d(t_i)} = 3\,\mathrm{a_i t}_i^2 + 2\,\mathrm{b_i}\, t_i + c_i \tag{10}$$

In time section $(\mathrm{t_i}, \mathrm{t_{i+1}})$, the $t_1, t_2, lon_1, lon_2, v_{lon1}, v_{lon2}$ are known, take them in (9) and (10),we can get:

$$\begin{aligned} lon(\mathrm{t_1}) &= \mathrm{a_1 t_1^3} + \mathrm{b_1 t_1^2} + c_1 t_1 + d_1 = lon_1 \\ lon(\mathrm{t_2}) &= \mathrm{a_1 t_2^3} + \mathrm{b_1 t_2^2} + c_1 t_2 + d_1 = lon_2 \\ v_{lon1} &= 3\,\mathrm{a_1 t_1^2} + 2\,\mathrm{b_1}\, t_1 + c_1 \\ v_{lon2} &= 3\,\mathrm{a_1 t_2^2} + 2\,\mathrm{b_1}\, t_2 + c_1 \end{aligned} \tag{11}$$

Solving equation (11) to the interval $(\mathrm{t_1}, \mathrm{t_2})$ of the Hermite polynomial coefficient a_1, b_1, c_1, d_1, so we can get:

$$\begin{aligned} lon(\mathrm{t}) &= \mathrm{a_1 t^3} + \mathrm{b_1 t^2} + c_1 t + d_1 \\ v_{lon1} &= \frac{dlon(\mathrm{t})}{dt} = 3\,\mathrm{a_1 t^2} + 2\,\mathrm{b_1}\, t + c_1 \end{aligned} \tag{12}$$

978-1-5386-0437-3/17/$31.00©2017 IEEE

The Eq. (12) is the interpolation polynomial in interval (t_1, t_2). Hence, the longitude and speed along longitude can be obtained at any time interval by Eq. (12). Correspondingly, the latitude and speed along latitude can be obtained as well. For the original AIS sequence, the two Hermite (t_i, t_{i+1}) using the above equations, we can obtain the corresponding interval of n-1 interpolation polynomial like (12).

After interpolation, we can get the piecewise function about the time *t*. By combining the speed along longitude and latitude, and restored speed is $v = \sqrt{{v_{lon}}^2 + {v_{lat}}^2}$, and the course can be obtained by Eq. (13):

$$\theta = \begin{cases} ar\cos(\frac{v_{\mathrm{lon}}}{v})(v_{\mathrm{lon}} > 0) \\ 360 - ar\cos(\frac{v_{\mathrm{lon}}}{v})(v_{\mathrm{lon}} < 0) \end{cases} \tag{13}$$

B. cubic spline interpolation

After preprocessing the original data, the velocity of the longitude and latitude is obtained. Because the speed in the direction of longitude and latitude, and the longitude and latitude is continuous in time, so we can get a function about time for the speed v_{lon} in the direction of longitude, and the velocity v_{lat} in the direction of latitude respectively. Then, the spline function is integrated to obtain the latitude and longitude on the speed of the function. So we can obtain latitude and longitude, and the speed and course at any time. For the AIS sequence, in each sub segment $[t_i, t_{i+1}]$, set a three times $s_3(t)$, so:

$$s_3(\mathrm{t}_i) = v_{loni}, \mathrm{s}_3'(\mathrm{t}_0) = v'_{lon1} = a_{lon1}, \mathrm{s}_3'(\mathrm{t}_{i+1}) = v'_{lon(i+1)} = a_{lon(i+1)}$$

Order $h_i = \mathrm{t}_{i+1} - \mathrm{t}_i$,and $s_3'(t_i) = m_i$,so we can get:

$$\mathrm{s}_3(\mathrm{t}) = \varphi_0(\frac{t-t_i}{h_i})v_{\mathrm{loni}} + \varphi_1(\frac{t-t_i}{h_i})v_{\mathrm{lon(i+1)}} + \mathrm{h_i}\delta_0(\frac{t-t_i}{h_i})\mathrm{m_i} + \mathrm{h_i}\delta_1(\frac{t-t_i}{h_i})\mathrm{m_{i+1}} \tag{14}$$

In equation (14) $\varphi_0(\mathrm{t}) = (\mathrm{t}-1)^2(2\mathrm{t}-1)$, so:

$$\varphi_1(\mathrm{t}) = \mathrm{t}^2(-2\mathrm{t}+3)\varphi_0(\mathrm{t}) = t^2(\mathrm{t}-1)$$

On (14) for the two order, in $[t_i, t_{i+1}]$ we have:

$$\begin{cases} \mathrm{s}_3''(\mathrm{t}_i) = 6\dfrac{v_{lon(i+1)} - v_{loni}}{h_i^2} - \dfrac{4m_i + 2m_{i+1}}{h_i} \\ \mathrm{s}_3''(\mathrm{t}_{i+1}) = -6\dfrac{v_{lon(i+1)} - v_{loni}}{h_i^2} + \dfrac{4m_i + 2m_{i+1}}{h_i} \end{cases} \tag{15}$$

In order to ensure the continuity of the two derivative, so:

$$\frac{m_{i-1} + 2m_i}{h_{i-1}} + \frac{2m_i + m_{i+1}}{h_i} = 3(\frac{v_{loni} - v_{lon(i-1)}}{h_{i-1}^2} + \frac{v_{lon(i+1)} - v_{loni}}{h_i^2}) \tag{16}$$

Order: $\alpha_i = \dfrac{h_{i-1}}{h_{i-1} + h_i}$,

$$\beta_i = 3\left[(1-\alpha_1)\frac{v_{loni} - v_{lon(i-1)}}{h_{i-1}} + \alpha_i \frac{v_{lon(i+1)} - v_{loni}}{h_i}\right]$$

Then the expression of (16) is:

$(1-\alpha_i)m_{i-1} + 2m_i + \alpha_i m_{i+1} = \beta_i$.

We know that $m_0 = v'_{lon0}, m_n = v'_{lonn}$.AIS series can be obtained on the $m_1, m_2 \ldots m_{n-1}$ equations (17):

$$\begin{cases} 2m_1 + \alpha_1 m_2 = \beta_1 - (1-\alpha_1)v'_{lon0} \\ (1-\alpha_1)m_1 + 2m_2 + \alpha_2 m_3 = \beta_2 \\ \quad\cdots\cdots \\ (1-\alpha_{n-2})m_{n-3} + 2m_{n-2} + \alpha_{n-2}m_{n-1} = \beta_{n-2} \\ (1-\alpha_{n-1})m_{n-2} + 2m_{n-1} = \beta_{n-2} - \alpha_{n-1}v'_{lonn} \end{cases} \tag{17}$$

The coefficient matrix is obtained by solving the equations (18).

$$A = \begin{bmatrix} 2 & \alpha_1 & & & 0 \\ 1-\alpha_2 & 2 & \alpha_2 & & \\ & \cdots & \cdots & \cdots & \\ & & 1-\alpha_{n-2} & 2 & \alpha_{n-2} \\ 0 & & & 1-\alpha_{n-1} & 2 \end{bmatrix} \tag{18}$$

After obtaining the coefficient matrix, we can get a piecewise spline function solution of v_{lon} and v_{lat} on time *t*. Then we can get the corresponding latitude and longitude by integrating the velocity in the direction of longitude, we can obtain the course through the Eq. (13).

IV. EXPERIMENT

In order to validate the proposed restore algorithm, we choose 163 AIS data of the ship (call sign HAIYOU668, MMSI: 413802276, ship length 120m, Class-A ship station: the transmission time interval is 10s) in October 10, 2016 in Wuhan. The coordinates, original speed and acceleration, original course and rate of turn are shown in *Fig. 3*, *Fig. 4, and Fig. 5,* respectively.

Fig. 3. Trajectory of raw AIS data

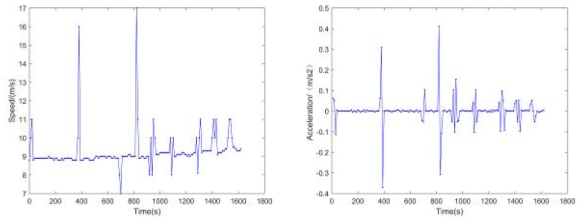

Fig. 4. Original speed and acceleration

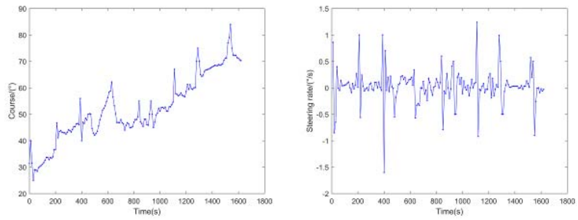

Fig. 5. Original course and rate of turn

There are too many inaccuracies in the original data, the length of the ship is 120 meters, the maximum acceleration is 0.028 m/s^2. In this voyage, the speed is no more than 10 knots, the maximum rate of turn is 1.23 °/s. After screening, the correct data are shown in *Fig.6*, *Fig.7* and *Fig.8*, respectively.

Fig. 6 AIS trajectory points after cleaning

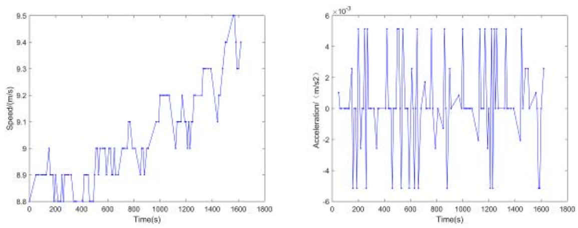

Fig. 7. Speed and acceleration after cleaning

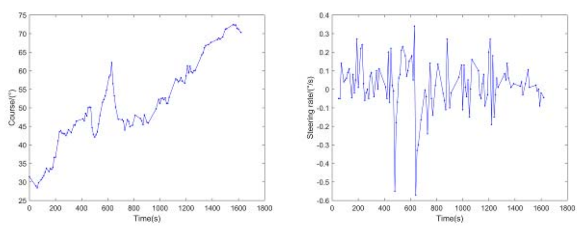

Fig. 8. Course and rate of turn after cleaning

After data cleaning, 110 correct data are obtained. The speed, acceleration, course and rate of turn of the cleaned data are fitted to the actual data, which means the inaccurate data has been deleted.

To verify the validity of the two methods presented in this paper, we choose 50 correct AIS data, and delete 5 points manually in a row. Then, the deleted track points are restored with the remained 45 data, and compared with the original data. The results are shown in *Fig.9* and *Fig.10*.

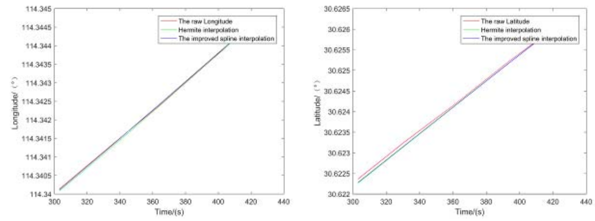

Fig. 9. Repair comparison of Latitude and Longitude

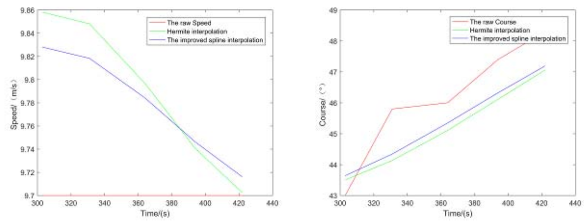

Fig. 10. Repair comparison of Speed and Course

To analyze the accuracy of longitude and latitude, the inaccurate of longitude and latitude between restored points and original points are transfer into distance. The average value and mean square inaccurate of the two kinds of restoration methods are shown in Table.1 and Table.2.

TABLE I. Mean value of inaccurate in two methods

	Distance	Speed	Course
Hermite	7.301989	0.089212	-0.73175
Cubic spline	6.533656	0.078576	-0.91702

TABLE II. The inaccurate variance of the two methods

	Distance	Speed	Course
Hermite	4.004335	0.060271	0.731704
Cubic spline	2.637348	0.042466	0.751654

From the tables, we can conclude that the improved cubic spline interpolation method performs better. The piecewise cubic Hermite interpolation restore the latitude and longitude by construct a unique cubic polynomial. The derivative of the cubic polynomial about the time is continuous. Hence the speed is relatively smooth. But the change of speed wasn't taken into consideration, so the speed is prone to change suddenly in each interval. Therefore, the fitting effect is poor. On contrary, the derivative of the improved cubic spline interpolation about the time is smooth. The position inaccurate is about 6.5 m, the speed inaccurate is about 0.07 m/s, the angle inaccurate is about 0.91°.

After cleaning the original AIS data with inaccurate, the AIS sequences were restored by the improved cubic spline interpolation. The lost data after cleaning is from 100th to 115th. The experimental results are shown in *Fig.11*, *Fig.12* and *Fig.13*, respectively.

978-1-5386-0437-3/17/$31.00©2017 IEEE

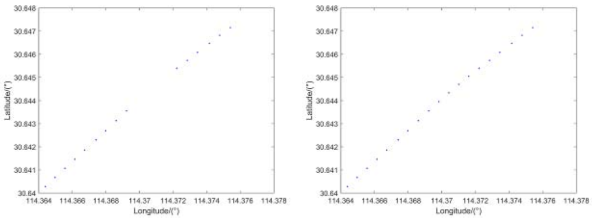

Fig. 11. Track points before and after restoration

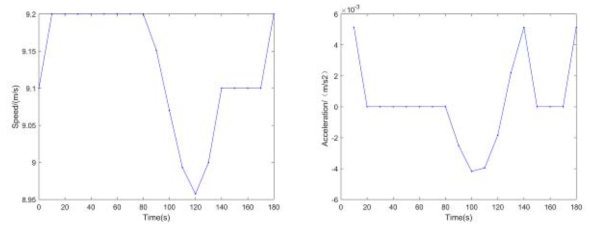

Fig. 12. The speed and acceleration after restoration

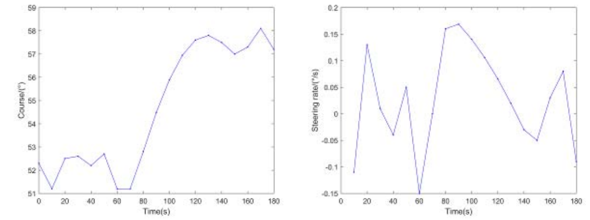

Fig. 13. The course and rate of turn after restoration

V. CONCLUSION

In this paper, five categories of inaccurate in AIS data are presented, and correspondingly, we designed five rules to clean the inaccurate according to the ships' maneuverability. Field experiment indicates that the five rules could delete the inaccurate data effectively. In order to restore the deleted and lost AIS data, piecewise cubic Hermite interpolation and cubic spline interpolation are employed. And we use real AIS trajectories to validate the accuracy of the two interpolation methods. The result shows that the cubic spline interpolation can restore the fragmentary AIS data better.

However, the cubic spline interpolation is effective only when the number of continuously lost data is less than five. In fact, more data will continuously lost when the ship passing through the curve channel and mountainous waterway, or encountering with the electromagnetic interference. In this paper, we didn't consider the situation that more than five track points are lost. In the future work, we will take this situation into consideration.

ACKNOWLEDGMENT

The present study is financial supported by the Double First-rate Project of WUT, the National Natural Science Foundation of China (No.51479155, No.61273234), the Excellent Dissertation Cultivation Funds of Wuhan University of Technology, Natural Science Foundation of Fujian Province (Grant No. 2015J05108) and Open Fund Project of Fujian Provincial Key Laboratory of Information Processing and Intelligent Control (Minjiang University) (No. MJUKF201727). The authors would like to express their sincere gratitude to anonymous referees for their valuable comments.

REFERENCES

[1] YAN Xin-ping, MA Feng, CHU Xiu-min, et al. Key technology of collecting traffic flow on the Yangtze River in Real-Time[J]. Navigation of China, 2010, 33:40-45.

[2] Pallotta G, Vespe M, Bryan K. Vessel Pattern Knowledge Discovery from AIS Data: A Framework for Anomaly Detection and Route Prediction[J]. Entropy, 2013,15(6):2218-2245.

[3] Steven Mascaro K B K A. Learning Abnormal Vessel Behaviour from AIS Data with Bayesian Networks at Two Time Scales[J]. Tracks a Journal of Artists Writings, 2010.

[4] Talavera A, Aguasca R, Galván B, et al. Application of Dempster–Shafer theory for the quantification and propagation of the uncertainty caused by the use of AIS data[J]. Reliability Engineering & System Safety, 2013,111:95-105.

[5] Aarsæther K G, Moan T. Computer vision and ship traffic analysis: Inferring maneuver patterns from the automatic identification system[M]. CRC Press, 2012.

[6] Michael Baldauf K B F M. Aspects of Technical Reliability of Navigation Systems and Human Element in Case of Collision Avoidance: Proceedings of the Navigation Conference and Exhibition, London, UK., 2014[C].

[7] Zhu Feixiang, Zhang Yingjun, Gao Jiang. Research on [J]. ship behavior data mining based on China navigation, 2012 (02): 50-54.

[8] Ma Feng, Yan Xinping, min Xiu min, et al. Correlation between signal failure and field strength of ship automatic identification system [J]. Journal of Dalian Maritime University, 2011 (03): 111-114.

[9] CHU Xiu-min, LIU Tong, MA Feng, et.al. Distribution characteristic of AIS signal field intensity along mountainous waterway[J]. Journal of Traffic and Transportation Engineering,2014,14(06):117-126.

[10] MA Feng, CHU Xiu-min, YAN Xin-ping, et al. Inaccurate Distinguish of AIS Based on Evidence Combination[J]. Journal of theoretical and applied information technology, 2012, 45(1):83-90.

[11] MA Feng, CHU Xiu-min, LIU Chen-guang.The inaccurate distinguishing of automatic identification system based on improved evidence similarity[C]IEEE. 2th International Conference on Transportation Information and Safety. Wuhan, China. IEEE, 2013:715-722

[12] Liu Xinglong, Yi Xiu min, Ma Feng, et al. Abnormal dynamic information screening method for AIS message [J]. Journal of traffic and transportation engineering, 2016 (05): 142-150.

[13] Liu Xinglong, Yi Xiu min, Ma Feng, et al. Research on the method of PCR6 target fusion recognition based on AIS [J]. Journal of Wuhan University of Technology, 2015 (08): 42-50.

[14] Liu Liqun, Wu Chaozhong, Zhu Duanfeng, et al. Study on ship trajectory restoration based on Vondrak filtering and three spline interpolation [J]. traffic information and safety, 2015 (4): 100-105. (in Chinese)

[15] Nguyen V, Im N, Lee S. The Interpolation Method for the missing AIS Data of Ship[J]. Journal of Navigation and Port Research, 2015,39(5):377-384.

[16] Liu C, Chen X. Inference of Single Vessel Behaviour with Incomplete Satellite-based AIS Data[J]. 2013,66(6):813.