



## **A MODEL FOR FUZZY DATA CORREALATION OF AIS AND RADAR**

<sup>1</sup>Liu Chang, <sup>1</sup>Cao Ming-zhi, <sup>1</sup>Han Feng, <sup>1,2</sup>Shi Gui-ming and <sup>1</sup>Liu Ren-jie

<sup>1</sup> Dalian Maritime University, Information Science and Technique College

Dalian, China, 116026

<sup>2</sup>Dalian Institute of Science and Technology, Dalian, China, 116032

Emails: liuchang20080123@sina.com

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*Abstract- With the development of Automatic Identification System (AIS), more and more vessels are equipped with AIS device, which is a new tool for vessel monitoring and marine safety. In this paper, we compared the function of AIS and radar, the traditional tool for Vessel Traffic Service (VTS). And then we discussed the necessity of data fusion of the same target from the two sensors of AIS and radar. According to the characteristic and the difference of tracking performance of AIS and radar we proposed a fuzzy correlation method for target tracking and data fusion. The experiment shows that the proposed method is correct and efficient and it can improve the performance and the stability of VTS.*

**Index terms:** Data fusion, fuzzy correlation, target tracking, Automatic Identification System (AIS), radar.

## I. INTRODUCTION

VTS (Vessel Traffic Service) is a system of collecting and processing the traffic data, and providing vessels with service. Up to now, many VTS systems have been established in world-wide ports. In China, there have been 22 VTS systems covering with most of water area. VTS played an important role in traffic safety, efficiency and environment protection.

In VTS, radar is the main tool for tracking vessel targets and collecting the navigation data. With the establishment of shore-based AIS [1-3], VTS can get target data such as dynamic, static and navigation information. For the administration of VTS covered by multiple radars, the cross section data can be collected by near radars [4-7]. When the shore-based AIS used in the processing, the track data can be got not only by radar but by AIS. For such a condition, we need a multiple sensors processing of data fusion method [8-11]. It can correlate the data from different sensors and establish the target tracking [12-18], which can improve the tracking performance of VTS.

In this paper, we discuss the fuzzy correlation and the data fusion of radar and AIS. The paper is organized into seven parts. The first part is introduction. The second part discusses tracking performance difference between radar and AIS. The third part discusses difference of target data category and precision of radar and AIS. The fourth part discusses the time calibration of target data. The fifth part studies the correlation method and the target data fusion. The sixth part presents the experiment and the result analysis. The final part provides the conclusion.

## II. DIFFERENCE OF TARGET TRACKING PERFORMANCE OF RADAR AND AIS

The main differences of target tracking between radar and AIS are shown as follows.

### a. Automatic identification function

Radar can not identify the targets automatically. Its tracking method is based on the echo video signal from receiver, which includes detection of target, estimation of location, calculation and saving of dynamic parameters, track extrapolation and fusion. But AIS can automatically identify the target. It can receive the MMSI (Marine Mobile Service Identified), dynamic and navigation related data [4]. It can realize the tracking target automatically.

#### b. Target data

The target data by multiple radars has the problem of time asynchronous. The precision of coordinate and measurement are different which causes the change of the data from the same target. VTS center should make the data fusion to keep target tracking. For shore-based AIS, the data are received from the same equipment. So the problem of time asynchronous does not exist. But the problems of coordinate and precision should be resolved too.

#### c. Reliability of target tracking

Target data collected by radar is influenced by the sea clutter, the false echo and the low tracking resolution. So the problems of radar target tracking exist, such as false-tracking, no-tracking, lost-tracking and cross-tracking. In AIS tracking, such conditions do not exist. The automatic identification can improve the reliability of tracking performance.

#### d. Range of target tracking

Within radar detection range, all targets can be detected. In AIS coverage area, only the targets equipped with AIS can be tracked. Additionally, the communication capacity of AIS network is limited [2].

From the analysis above, AIS has a better tracking performance than radar in VTS. AIS data can be considered as the basis in the fusion processing of target tracking.

### III. DIFFERENCES OF DATA CATEGORY AND PRECISION

#### a. Differences of data category

AIS can get more target data than radar. The collected data is the static, dynamic and navigation related data etc. Radar gets only dynamic data. It can not obtain the static data or the navigation related data.

#### b. Differences of the location data

AIS target data comes from ship-borne GPS which is the position of GPS antenna. Radar target data comes from radar echo by A/D conversion and detection processing. The precision of AIS is

superior to radar which is better than 10 meters. The precision of radar becomes much lower when the distance between radar and target is longer. AIS data is expressed by longitude and latitude. Radar is expressed by polar coordinate.

#### c. Differences of course, speed and other data

AIS get the speed, course, and heading data of targets from ship-borne GPS and compass. Vessel size data and the position of GPS antenna are input manually. The course and speed of radar is got by course extrapolation which is associated with the history data and may have a time-delay. The size data output from radar is calculated by target plotting, which has bigger error than the real size. This error changes with the vessel navigation state.

Besides, the collection of target dynamic data of radar and AIS is asynchronous [19-21]. The updating period of data is different. The period of radar is 3 seconds but the period of AIS is changed from 2 seconds to 3 minutes according to the different navigation states of the target.

According to the difference and characteristic of radar and AIS analyzed above, in the calibration and correlation of target data, we take the AIS target data as the reference data for the calculation. Meanwhile we take the target position data as the most basic correlated data, and the next is the data of speed and course. The fuzzy correlation is the premise of the multi-sensor fusion.

## IV. CALIBRATION OF TARGET DATA

The multi-sensor fusion in the VTS belongs to the characteristic level target status data fusion [22-24]. The calibration and correlation processing to the multi-sensor target information is the basis of the fusion. The function of data calibration is to unify the time and space reference point of various sensors, which is the premise of data correlation. The function of data correlation is to judge whether the data (existing deviation) of various sensors comes from the same target. If the data correlates we can judge the data belonging to the same target and can be made fusion.

Generally, we used UTC from GPS as the unification time reference. The unification earth coordinate is WGS-84. The sampling time at which each sensor gathers the target position data, is different, and probably the coordinate is different. All the gathering position data must be changed into the WGS-84 coordinate, and must use the extrapolation, the interpolation or other means to correct the corresponding time of the dynamic data such as target location. And then we

make correlated processing of the characteristic data. There are many methods of time calibration, such as the linear time calibration (twice interpolation) with the interpolation, the throwing time calibrating with the interpolation (three times of interpolation), the Lagrange time calibrating at the interpolation (n times of interpolation), the Newtonian time calibrating at the interpolation and so on. According to the target information characteristic of AIS and the radar, here we used the extrapolation method, considering the AIS data as the datum.

In VTS, the scanning period of radar is 3 s, and the data updating period of AIS is from 2 to 10 s. In other words, the biggest difference of updating period of radar and AIS cannot exceed 10 s. Within this period, the value of target positions changes in a certain range and they should be calibrated with a unique clock. But for the vessels, of which the data of speed and course is not changed very much, may be considered as the uniform linear motion. According to the analysis above we adopted the extrapolation equation to calibrate the data time.

Suppose the gathering data of longitude, latitude, speed and course of radar target in  $t_1$  is respectively  $Lo_{R1}$ ,  $La_{R1}$ ,  $V_{R1}$  and  $C_{R1}$ . The data of longitude, latitude, speed, course of AIS target in  $t_2$  is respectively  $Lo_{A2}$ ,  $La_{A2}$ ,  $V_{A2}$  and  $C_{A2}$ . And we suppose  $t_1 > t_2$ . The difference  $\Delta t$  of  $t_1$  and  $t_2$  is defined as in (1).

$$\Delta t = (t_1 - t_2) \quad (1)$$

In  $\Delta t$  the data of speed and course of target is invariable. At the time of  $t_1$ ,  $Lo_{A1}$  and  $La_{A1}$  of AIS target position are expressed as follows in (2) and (3).

$$Lo_{A1} = Lo_{A2} + V_{A2} \Delta t \sin C_{A2} \quad (2)$$

$$La_{A1} = La_{A2} + V_{A2} \Delta t \cos C_{A2} \quad (3)$$

For the vessel targets of large or middle scale, the supposition of the data of speed and course is invariable and generally it may not cause a big error. But the vessel targets of small size may have a good maneuverability. When the changing rate of speed and course changes a lot, it may cause a certain error. For this condition, we may judge those small ships by identifying them according to the data of vessel size collected from AIS. And we calculate the changing rate of speed and course to revise the equation (2) and (3).

The position data gathered by AIS is the position of GPS antenna on the ship. In order to make the correlated processing with the radar position data, we also need to transform the above

extrapolation target of the GPS antenna position into the center position data of the target, according to the size data and the position data of GPS antenna of the vessel.

The discussion above is only according to the condition of one target. For the multi-target we need to establish a data set of target position obtained by AIS, and then make correlation processing with the radar target data set.

## V. FUZZY CORRELATION MODEL OF THE TARGETS

In real-time tracking of multiple targets the data collected by multi-sensor from the same source always has some similar physical characteristics. But because of the differences of influence and interference of the sensors performance, these characteristics are not identical. Correlation data processing makes use of such similar characteristic of data to judge whether the data comes from the same target. The data collected by the shore-based AIS, which can be used for the fuzzy correlation, including the dynamic information of target-ship such as position, speed, course and the size of ship as well as the position of the GPS antenna. In the processing between the two targets of AIS and radar, we make a group of data. Usually, we take the calibrated data of longitude, latitude, speed and course of the target as the basis data of the correlation processing. Because the target data of length, width and course outputting from radar has a lot of differences from the real-time information, we divided the targets into three categories of large, medium and small.

The multi-group of fusion data can use the fuzzy correlation to achieve the same target from radar and AIS. The method of fuzzy correlation of position, speed and course will be discussed as follows. First, the data of longitude, latitude, heading and speed of the target which has been calibrated makes up of a group of input vectors waiting to be judged: *track (lat, lon, crs, spd)*. By the correlation function we count the membership of the two vector groups:  $g (g \in [0,1])$ , and the correlation membership shows the degree of correlation of the data. The more close is the data the higher is the value of the correlation membership. We established the different equations of the correlation membership for the different vector. And how to establish the correlation functions of the data of latitude, longitude, speed and course will be discussed in the following.

The fuzzy correlation of latitude and longitude can establish geometric models as shown in figure 1 because of the high precision of the position data from radar and AIS. The  $x$ -axis denotes the

difference between the two parameters of longitude; the  $y$ -axis denotes the correlation membership of  $g$ . It shows that the correlation membership of the two groups of data reach the maximum value only when the longitudes (or latitude) are equal. When the precision of the data is not high enough, we can put the triangular spire into flat-roofed. For other information of course and speed, the precision of radar is not very high enough, so we adopt the membership functions as shown in figure 2 and figure 3. The flat-roofed part and the slope of bias in the figure are correlated with the precision and the change of the speed.

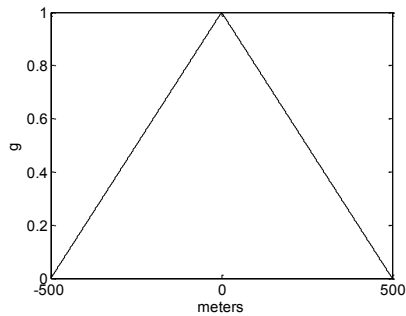


Figure1. Correlation equation of lon. and lat.

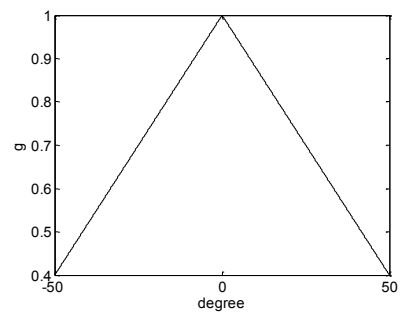


Figure 2. Correlation equation of course

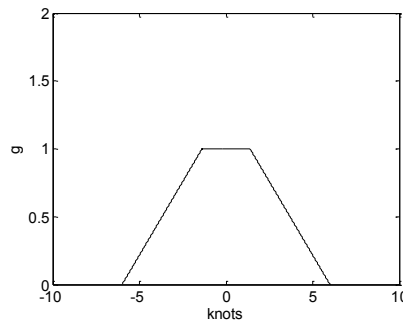


Figure 3. Correlation equation of speed

Figure 4 is the principle frame of fuzzy correlation system. As shown in figure 4, the input is the vector  $g (g_{lat}, g_{lan}, g_{crs}, g_{spd})$  of the two targets. Firstly, we calculate the correlation membership  $g$  of each vector and then compare with the threshold  $g_0$ . When the correlation membership of data is all satisfied with the condition of fuzzy arbiter, the two tracking data can be judged as from the same target. But the fact should be noticed that the correlation membership of these two kinds of data is “add”.

The process of the judgment is described as follows. Firstly, the fuzzy model decides whether the fusion level of longitude and latitude  $g_{lat}$ ,  $g_{lon}$  is satisfied with the equations of  $g_{lat} > g_o$  and  $g_{lon} > g_o$ . And then it makes the judgment of course and speed, according to the equations of  $g_{crs} > g_o$  and  $g_{spd} > g_o$ . If all the conditions cannot be satisfied, the output value is 0. We get the conclusion that the track information of the two targets is not correlated, that is, they are not the same target and can not be fusion. Otherwise, when the conditions of  $g_{lat} > g_o$  and  $g_{lon} > g_o$  and  $g_{crs} > g_o$  and  $g_{spd} > g_o$  are all satisfied, the output value is 1. And we can conclude that the two targets are correlated and they are the same vessel and can be fused.

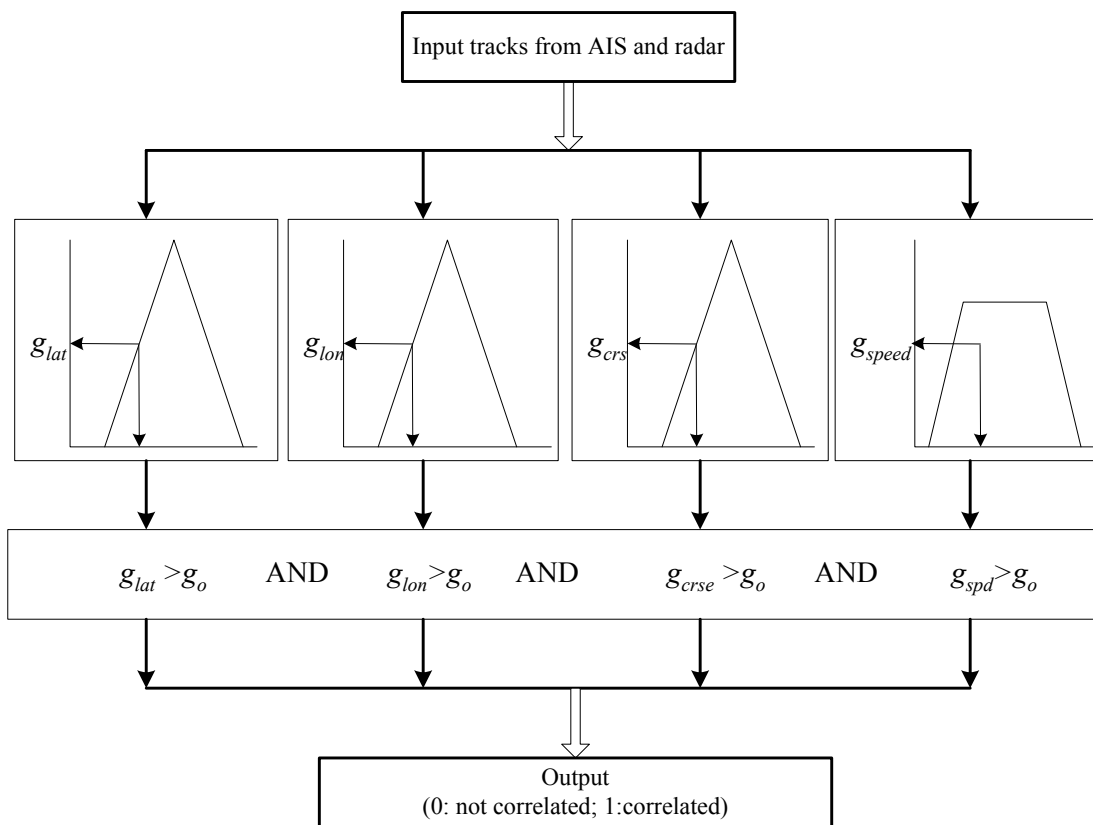


Figure 4. Block of fuzzy correlation theory

Use the correlation algorithm above we can get the track information from different sensors of the same target, the one is AIS and the other is radar. The MMSI code is obtained from the AIS track information. Compared with the track-information of the target, we can appoint the new data report to one of the data collection following.



(1)A data collection of new targets: to establish a report of new targets, which are not be detected up to now. A new data collection will be created and the new report will be saved in it.

(2)A data collection of existed targets tracking: it means to establish a tracking report of existed targets, which have been detected. The data report should be saved in this collection.

(3)A false alarm: that is to assume a false target detected by the sensor and then delete the report according to the improved study.

Besides, the fuzzy correlation algorithm can be expanded by adding the types of tracking data into the vector set.

## VI. EXPERIMENT AND ANALYSIS

In the experiment we select three vessels' data synchronously from JRC-radar and SAAB AIS. Figure 5 shows the experimental set-up of JRC radar and figure 6 shows the shore-based SAAB AIS. The targets collected by radar and AIS display in figure 7 and figure 8. And the experimental data is shown in table 1. Suppose the position of local radar is (N 38°52.0249', E 121°31.214') shown as in figure 7. The calculated position data from radar is shown in table 2. And then we obtain the result of  $g$  ( $g_{lat}$ ,  $g_{lan}$ ,  $g_{crs}$ ,  $g_{spd}$ ) of each target by the experiment. The result value of the correlation memberships are shown in table 3.



Figure 5. JRC- radar



Figure 6. SAAB AIS of BS 410

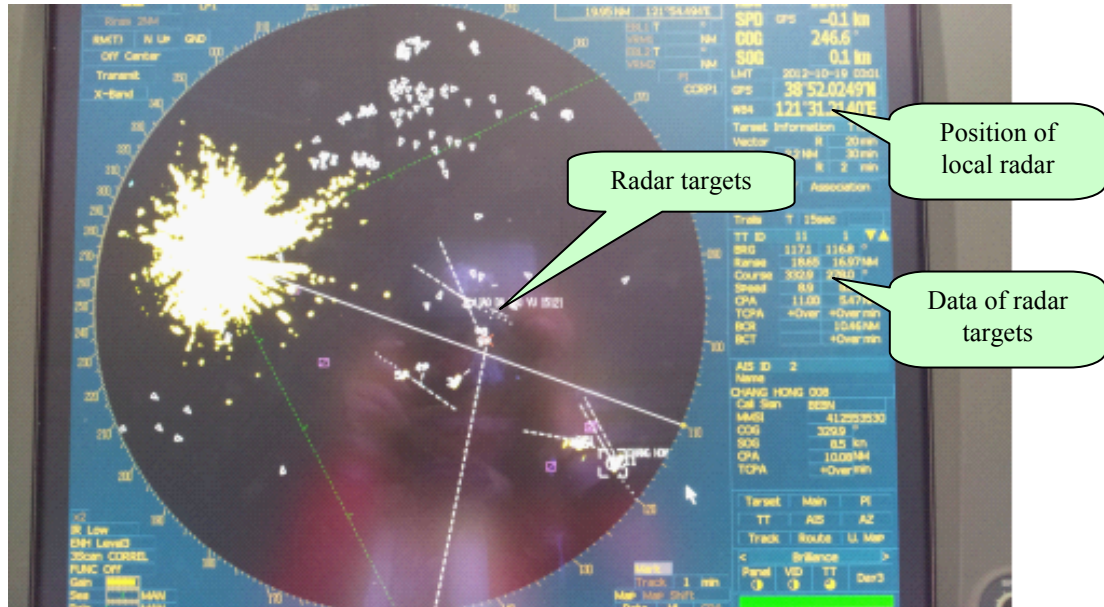


Figure 7. Display of targets collected by radar

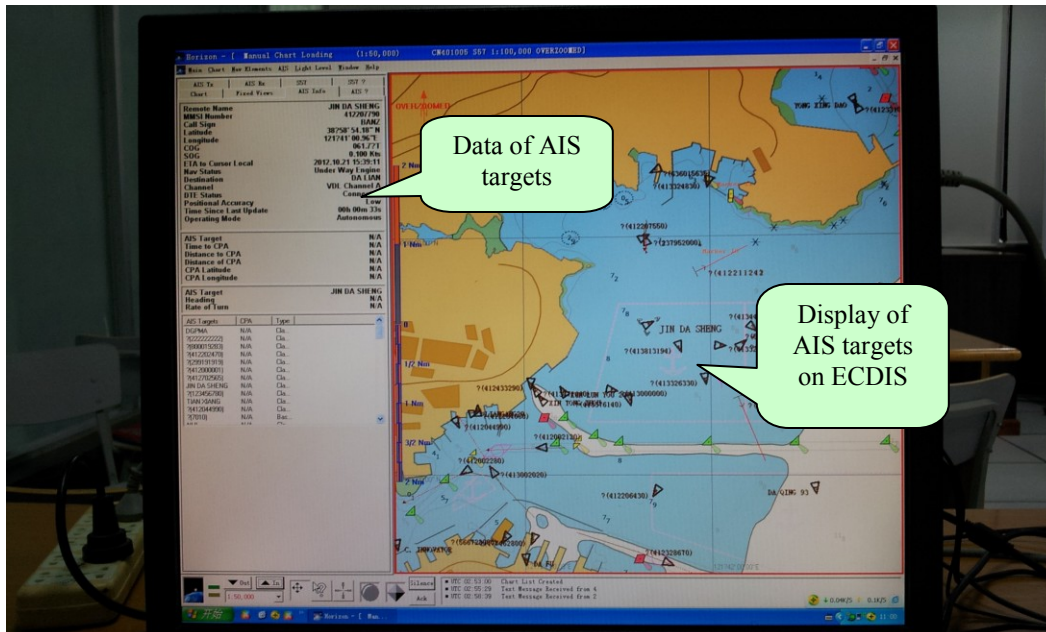


Figure 8. Display of targets on ECDIS collected by AIS

Table 1: Collected ship data from AIS and radar

Target data		By Radar	By AIS
Ship 1	Target Position		N 38°45'09.06"E 121°47'03.26"

	Course	151.3°	148.0°
	Speed(knot)	15.1	15.0
	Bearing	118.9°	
	Range(n mile)	14	
Ship 2	Target Position		N 38°43'39.24"E 121°52'21.12"
	Course	153.5°	145.2°
	Speed(knot)	8.7	8.0
	Bearing	117.1°	
	Range(n mile)	18.4	
Ship 3	Ship Position		N38°44'29.57"E121°53'01.70"
	Course	330.3°	330.9°
	Speed(knot)	9.57	10.0
	Bearing	114.2°	
	Range(n mile)	18.7	

Table 2: Calculated ship position from radar

Target	Lat.	Lon.
Ship 1	N 38.7541°	E 121.7821°
Ship 2	N 38.7270°	E 121.8700°
Ship 3	N 38.7389°	E 121.8845°

In the experiment we supposed the  $g_o$  as 0.5. From table 3 we can see obviously that  $g_{lat} > g_o$  and  $g_{lon} > g_o$  and  $g_{crs} > g_o$  and  $g_{spd} > g_o$ . So the result of the fuzzy correlation is tested to be correct. And then we made data fusion of the target of ship 1 as an example. Figure 5-8 are respectively the fusion result of range, bearing, course and speed of ship1. According to the results of the experiment we can conclude that the method of fuzzy correlation we proposed is tested to be correct and efficient.

Table 3: Result of correlation experiment

Target	$g_{lat}$	$g_{lon}$	$g_{crs}$	$g_{spd}$
Ship 1	0.8126	0.6358	0.9844	1
Ship 2	0.9295	0.5662	0.9004	1
Ship 3	0.6946	0.8439	0.9928	1

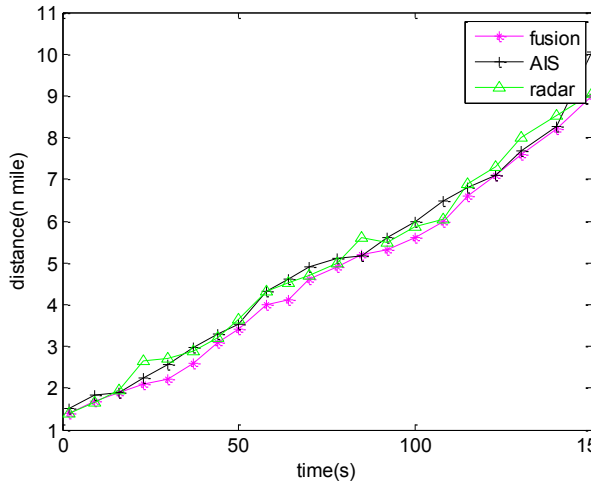


Figure 9. Range fusion result of ship 1

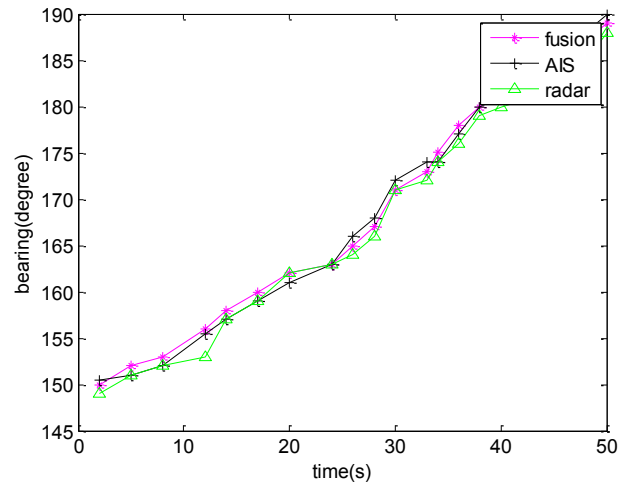


Figure 10. Bearing fusion result of ship 1

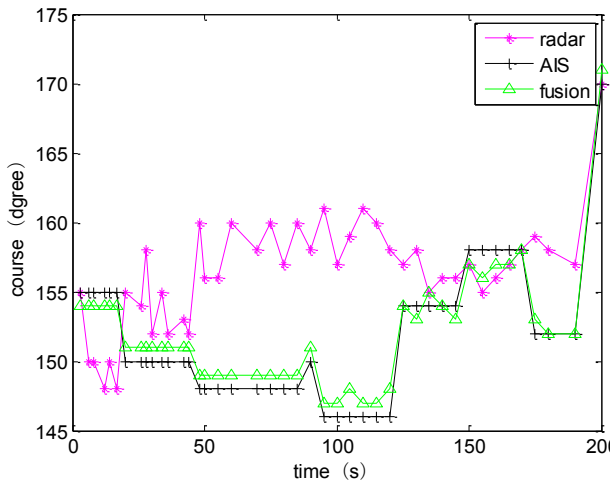


Figure 11. Course fusion result of ship 1

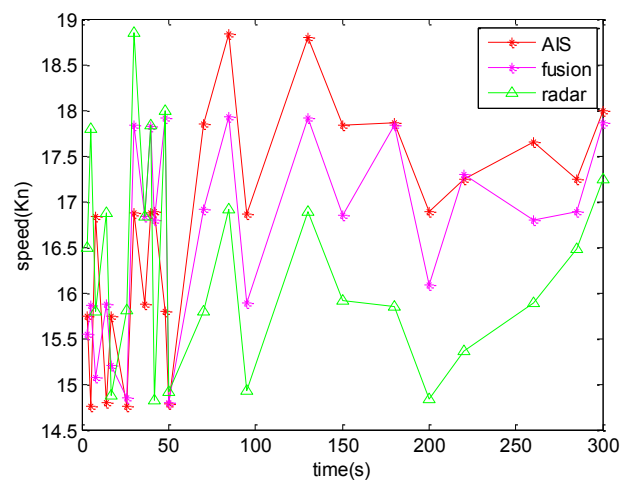


Figure 12. Speed fusion result of ship 1

## VII. CONCLUSION

The fusion of radar and AIS makes an important role in the targets tracking in VTS. This paper emphasizes on the problem of fusing the AIS data based on the fuzzy correlation algorithm. The method of estimating the position is according to the target tracking of AIS and radar. The proposed method realized the correlation of radar and AIS targets and it is tested to be reliable and efficient.

The advanced study should be how to utilize the other information of AIS, such as the size, type, gauge and other navigation information, in target tracking and data fusion. There will be more correlated condition for the judgment and the result will be more precise. For example, when the latitude, longitude, course and speed, the four parameters are very close, an additional judgment condition of the size or the heading of the ships will make the result more reliable and precise. The size of the ship can be estimated by the information output from the radar tracking and AIS statistic data.

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