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 forth 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.

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

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

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_{lan} 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.

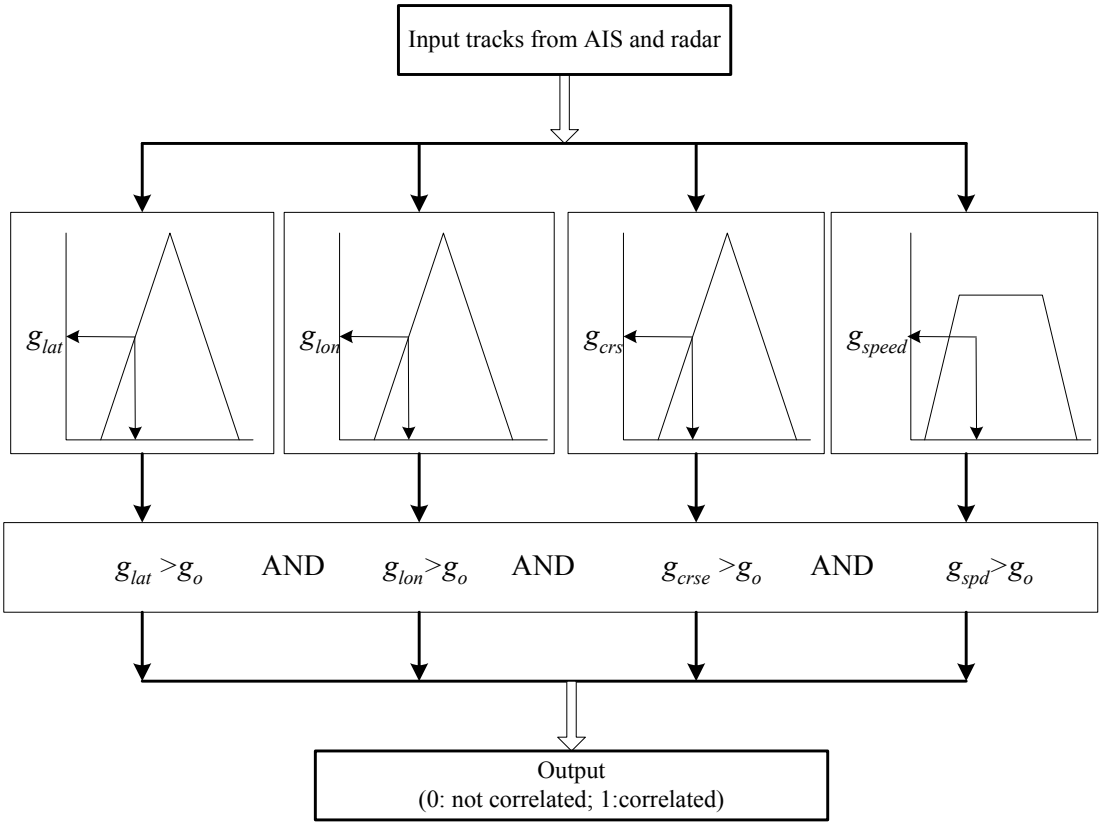

Figure 4. Block of fuzzy correlation theory

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.

Figure 5. JRC- radar

Figure 6. SAAB AIS of BS 410

	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.

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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