Development of Remote Radar/AIS Network System for Observing and Analyzing Vessel Traffic in Tokyo Bay

*Hideki Hagiwara[1], Ruri Shoji[1], Hitoi Tamaru[1], Shun Liu[2], Tadashi Okano[2]

[1]Tokyo University of Marine Science and Technology (E-mail: hagiwara@e.kaiyodai.ac.jp)
[2]Graduate School, Tokyo University of Marine Science and Technology

Abstract

Accurate vessel traffic observation is indispensable to carry out vessel traffic management, design of vessel traffic route, planning of port construction, etc. In order to observe the vessel traffic accurately without many efforts such as the use of a ship or car equipped with special radar observation system and the preparation of observation staff, the authors have been developing completely automated remote radar/AIS network system covering the main traffic area in Tokyo Bay. The composite radar image observed at Yokosuka and Kawasaki radar stations with AIS information can be seen on web site of Internet. In addition to the development of radar/AIS observation system, the software to analyze observed vessel traffic flow has been developed. This software has various functions such as automatic tracking of ship's positions, automatic estimation of ship's size, automatic integration of radar image and AIS data, animation of ships' movements, extraction of dangerous ship encounters, etc.

The configuration and functions of the developed remote radar/AIS network system are shown first in this paper. Then various functions of the software to analyze vessel traffic are introduced, and some analyzed results on the vessel traffic in Tokyo Bay are described demonstrating the effectiveness of the developed system.

Keywords: vessel traffic, radar/AIS network system, web site, automatic tracking

1. Introduction

Tokyo Bay is one of the most congested waters for vessel traffic in the world. If a serious maritime accident occurs, damage to economic activities and the natural environment will be incalculable. To prevent maritime accidents in congested waters and improve the efficiency of vessel traffic, it is important to know the vessel traffic characteristics and perform appropriate vessel traffic management. For the grasp of the vessel traffic characteristics, accurate vessel traffic observation and the analysis of that observation data are essential. Up to now, however, since the vessel traffic observation has needed expensive resources such as a ship or car equipped with special radar observation system and the experienced observation staff, the area and period of the observation has been limited.

In order to perform long-term and long-range vessel traffic observations in Tokyo Bay, the authors have been developing completely automated remote radar/AIS network system covering the main traffic area in Tokyo Bay. The project for establishing the radar network system was started in 2000 (1). The first radar station was tentatively set at the Sea Training Center of the Tokyo University of Mercantile Marine facing the entrance of Tokyo Bay. In December 2002, this radar station was transferred to the National Defense Academy in Yokosuka and its operation was officially launched. In September 2003, the second radar station was set at Higashi Ogishima in Kawasaki. With these two radar stations, the vessel traffic conditions in most part of Tokyo Bay could be displayed in real-time at the monitoring station in the Tokyo University of Marine Science and Technology (TUMSAT). In addition, the AIS receiver was installed at Kawasaki radar station, which enabled us to observe the names, positions, speeds, lengths, etc. of the ships equipped with AIS in Tokyo Bay (2). Now composite radar image observed at Yokosuka and Kawasaki radar stations with AIS information can be seen on web site of Internet.

From the beginning stage of the project, the software to analyze observed vessel traffic data has been developed. This software has various functions such as automatic tracking of ship's positions, automatic estimation of ship's size, automatic integration of radar image and AIS data, animation of ships' movements, extraction of dangerous ship encounters, etc. The configuration and functions of the developed remote radar/AIS network system are shown first below. Then various functions of the software to analyze vessel traffic are introduced, and some analyzed results on the vessel traffic in Tokyo Bay are described.

2. Remote Radar/AIS Network System

2.1 Configuration of the System

The remote radar/AIS network system is composed of two radar stations (Yokosuka radar station and Kawasaki radar station), AIS receiver installed at Kawasaki radar station, and the monitoring station located at the TUMSAT. The configuration of remote radar/AIS network system is shown in Fig.1. The radar antenna (length: 9 feet) of Kawasaki radar station and the AIS receiver are shown in Fig.2. Concerning the data transmission, constant Internet access via ADSL has been adopted between Yokosuka radar station and the monitoring station, whereas constant Internet access via optical communication line has been utilized between Kawasaki radar station and the monitoring station. The AIS receiving station attached to Kawasaki radar station has used the same optical communication line as the radar to transfer AIS data to the monitoring station. Fig.3 shows the composite radar image from Yokosuka and Kawasaki radar stations displayed on the screen of monitoring station in the TUMSAT.

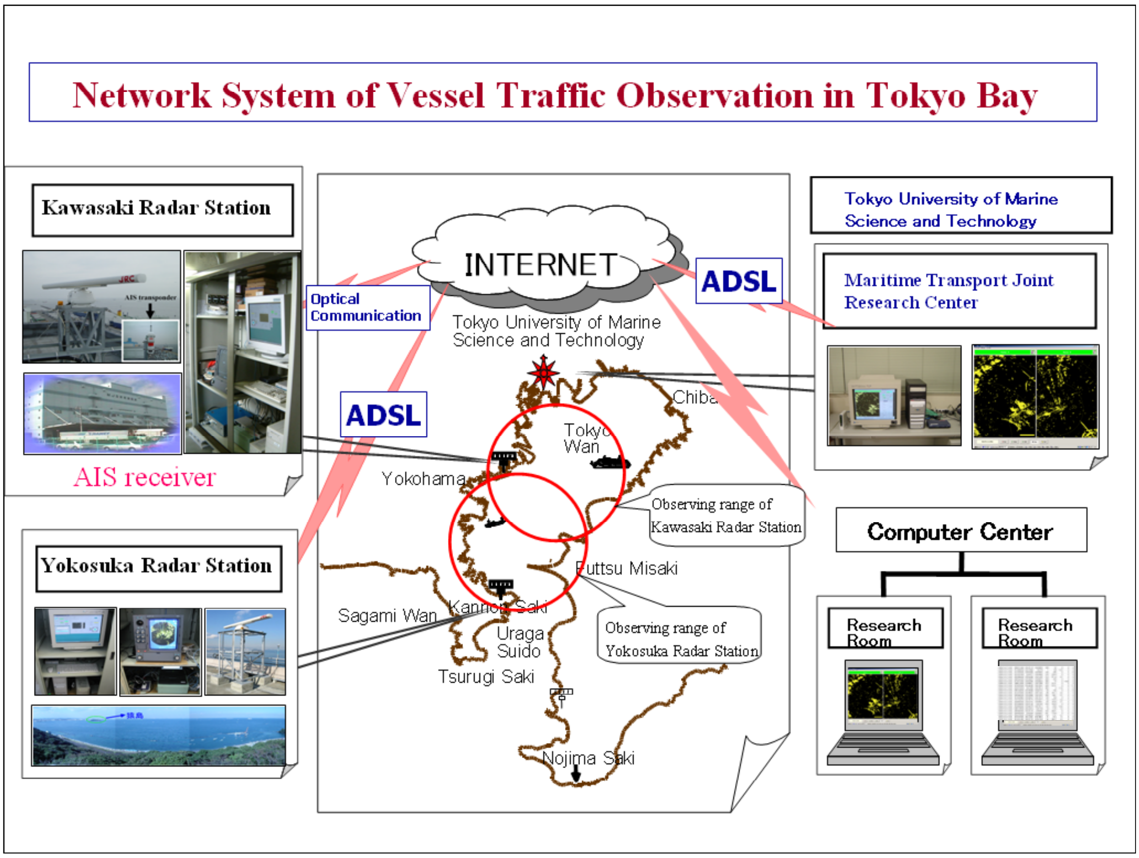

Fig.1 Configuration of remote radar/AIS network system for observing vessel traffic in Tokyo Bay

Fig.2 Radar antenna and AIS receiver at Kawasaki radar station

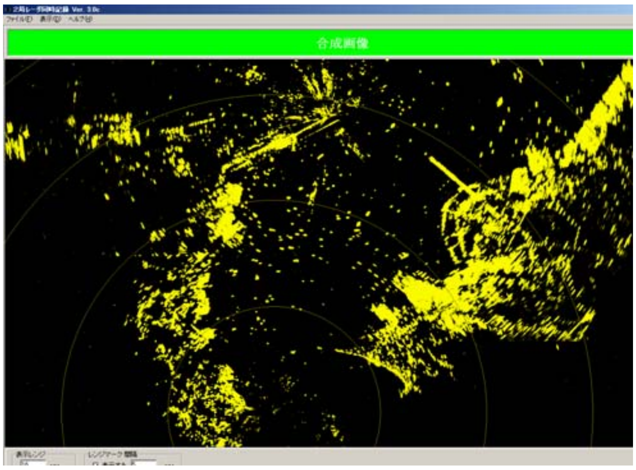

Fig.3 Composite radar image from Yokosuka and Kawasaki radar stations displayed on the monitoring screen

To start, adjust and end the operation of both radar stations are feasible on the screen of communication controller at the monitoring station. The adjusting function is comprised of radar image control functions (gain, STC, FTC, sweep/scan correlation, etc.) and data communication functions (image quality, compression ratio, etc.). The transmitted radar image is indicated on the screen at the monitoring station to observe the vessel traffic in Tokyo Bay in real time, meanwhile it is possible to record radar images and AIS data to analyze them later.

2.2 Displaying Radar/AIS information on Web Site

In order to distribute radar/AIS information to the public, the web server was installed in the monitoring station in 2005. The radar images observed at Yokosuka and Kawasaki radar stations as well as AIS data observed at Kawasaki radar station are sent to the web server from the communication controller. By accessing this web server via Internet (http://202.212.165.70/index.html), the composite radar image observed at Yokosuka and Kawasaki radar stations with the ships' positions and speed vectors obtained from AIS can be displayed in real time (Fig.4).

In addition to the composite radar image, the detailed AIS information can be displayed (Fig.5). In this menu, all ships' positions and speed vectors in Tokyo Bay obtained from AIS are displayed, and AIS information such as navigation state, speed over the ground, course over the ground, ship's heading, ship's length, ship's breadth, etc. of each ship can be shown by clicking each ship with the mouse button. In the future, various menus such as animation of radar image, displaying ships' tracks, ship density distribution, etc. will be added to this web site.

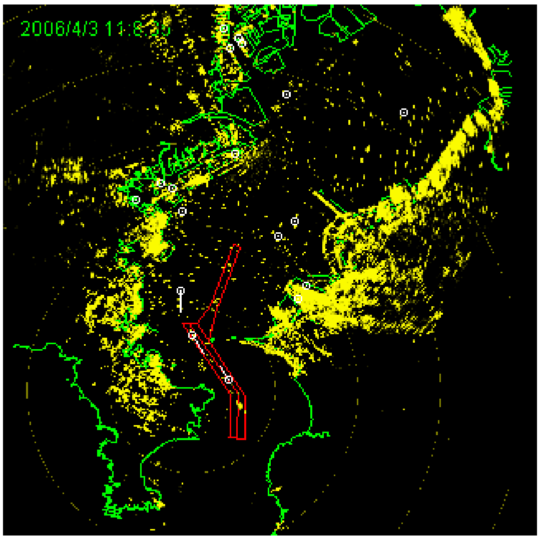

Fig.4 Composite radar image and ships' positions and speed vectors obtained from AIS on web site

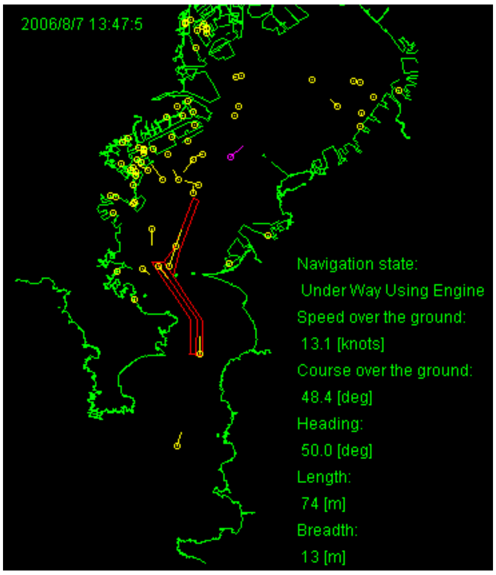

Fig.5 AIS information display on web site

3. Analysis of Vessel Traffic

3.1 Software for Vessel Traffic Analysis

To analyze vessel traffic observed by the remote radar/AIS network system, software for vessel traffic analysis has been developed. The main functions of the software are 'moving image', 'superposing display', 'plotting (manual tracking of ship's positions)', 'automatic tracking', and 'automatic tracking using AIS information'. Radar image data observed at constant intervals (e.g. one minute) are stored in the communication controller of the monitoring station, and used for the vessel traffic analysis. The display with 1,024 x 1,024 pixels is used when radar image is displayed on a PC screen. Coastlines, buoys and traffic routes are shown on the screen to find a ship's position easily.

The moving image function displays radar images at constant intervals on the screen as an animation, which is effective for grasping the vessel traffic flow over the whole observed area. The superposing display function superposes radar images as shown in Fig.6 (20:00-21:00 on 9 January, 2003), from which the ships' tracks are clearly identified.

Fig.6 Superposed radar images (interval: one minute)

The plotting function is for obtaining ship's track manually by clicking the ship image on the screen with the mouse button. The X-Y coordinates of each ship image is found, and ship's position data in time sequence are created for each ship.

The automatic tracking function is used for obtaining ship's track automatically. In this function, stationary objects on the radar screen which exist for longer than half of the observation period are removed first. Next, in each radar image, the objects in which the luminance of all involved pixels is 200 or more are extracted as the ships' images. (The luminance of each pixel on the screen ranges from 0 to 255.) The X-Y coordinates of the center of gravity of the ship image is regarded as the ship's position. Then ship's position and the number of pixels of each ship image are recorded. If all positions of some ship during 10 minutes exist inside the circle of 200m radius, that ship is regarded as the anchoring ship and removed from vessel traffic analysis.

After the above mentioned pre-processing, automatic tracking is carried out using the ship's position of each ship image on each radar image recorded at constant time intervals. (Hereafter, recording interval is assumed to be one minute.) When some ship's position appears first at time T_1 on the radar screen, two consecutive ship's positions at time T_2 and T_3 are investigated. Based on the ship's positions at T_1 and T_2, the ship's position at T_3 is predicted. If the actual position of ship image at T_3 is inside the sector centered around the predicted ship's position as shown in Fig.7 (i.e. if the error of ship's speed is smaller than 60% of the predicted speed, and the error of ship's course is smaller than 30 degrees), three consecutive ship's positions are identified as the positions of the same ship.

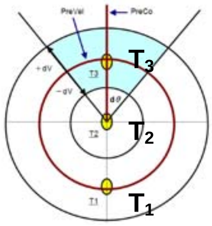

Fig.7 Start of automatic tracking using three consecutive ship's positions

Then based on the above three consecutive ship's positions at T_1, T_2 and T_3, the next ship's position at time T_4 is predicted. For this prediction, the ship's course between T_2 and T_3 and the average ship's speed between T_1 and T_3 are used. Comparing the distances between the actual ships' positions and the predicted ship's position at T_4, the nearest actual ship's position to the predicted ship's position is taken as the ship's position of the same ship at T_4. (If there is not a ship inside the circle of 300m radius centered around the predicted ship's position, this ship is considered to be lost.) Then using the ship's positions at T_2, T_3 and T_4, the next ship's position at T_5 is obtained. Repeating this procedure, the ship's positions at T_6, T_7, T_8, ----- (i.e. ship's track) can be determined.

Fig.8 shows the tracks of 707 ships which were automatically tracked and confirmed that the obtained tracks were correct. The radar images observed from 00:00 to 23:59 on 17 August, 2005 at intervals of one minute were used for these tracking. In this observation, the tracks of 1,277 ships were obtained by the automatic tracking function and 707 ships (55%) were correctly tracked.

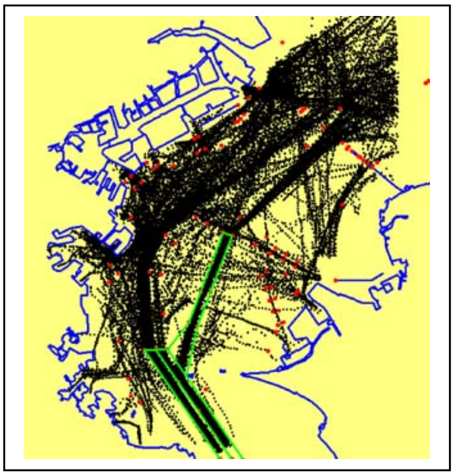

Fig.8 Ships' tracks obtained by automatic tracking function

The automatic tracking using AIS information function superposes AIS position on the ship image on radar screen and automatically tracks the center of ship image. In this function, the original AIS data are converted to AIS data corresponding to the time of radar observation. In general, there are 6 to 10 AIS positions in one minute, and after conversion there is only one AIS position at the time of radar observation.

In the case that AIS position is inside the ship image, regarding the AIS position as the origin of coordinates, the pixel's luminance around it is investigated first. The pixel is moved from the origin one by one in horizontal direction and vertical direction, and only if the pixel's luminance is 200 or more, the pixel's coordinate is recorded. By calculating the average coordinates from all coordinates recorded, the center of ship image is obtained. Next, course and speed from the center of previous ship image (one minute ago) to the center of present ship image are calculated; then the results are compared with COG and SOG in AIS data. Provided course difference is less than 5 degrees and speed difference is less than 20%, the found ship image is identified as a target transmitting AIS data.

In the case that AIS position is outside the ship image, regarding the AIS position as a center of circle, the point that pixel's luminance is 200 or more is searched by increasing the radius of the circle. When that point is found, the center of ship image can be calculated and the ship image is identified as a target as mentioned above. Fig.9 shows an example of automatic tracking of the center of ship image using AIS information. In Fig.9, white circle and black circle indicate AIS position and the center of ship image, respectively. The advantage of this automatic tracking using AIS information is high reliability of tracking, i.e. no risk of target swapping which often occurs in automatic tracking when the distance between two ships is close.

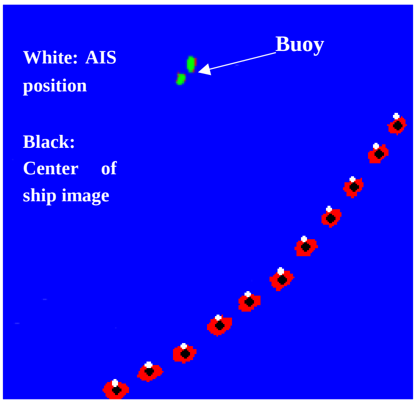

Fig.9 Example of automatic tracking using AIS information

3.2 Estimation of Ship's Length from Ship Image

In general, the risk of collision is proportional to the ship's length and the traffic capacity of traffic route is inversely proportional to the square of ship's length. Thus it is essential to obtain the length of each ship in vessel traffic analysis. The method for estimating ship's length from the size of ship image on radar screen was developed. First, for each ship whose length was known by visual observation or AIS in 2004, the relation between the size of ship image and the distance from Yokosuka radar station was investigated while the ship's positions were located between 4 miles and 6 miles from Yokosuka station, and the first-order regression formula was derived by the least mean square method as shown in Fig.10. Using this regression formula, the size of ship image at 5 miles from Yokosuka station was estimated.

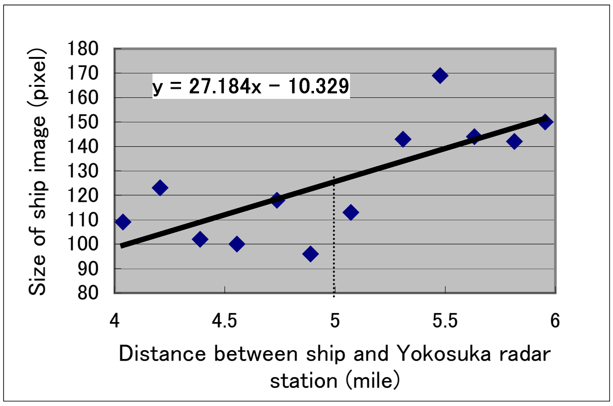

Fig.10 Size of ship image on radar screen versus distance from Yokosuka radar station

Then the relation between ship's length and the size of ship image at a distance of 5 miles from radar station was investigated, and the second-order regression formula was derived by the least mean square method as shown in Fig.11. During the automatic tracking process mentioned in 3.1, the position and the size of ship image of each ship are recorded at constant time intervals. So, for each ship whose length is unknown, the size of ship image at a distance of 5 miles from Yokosuka radar station is calculated as shown in Fig.10. Then using formula shown in Fig.11, the length of each ship can be estimated. This estimating method can be also applied to the ship images observed by Kawasaki radar station.

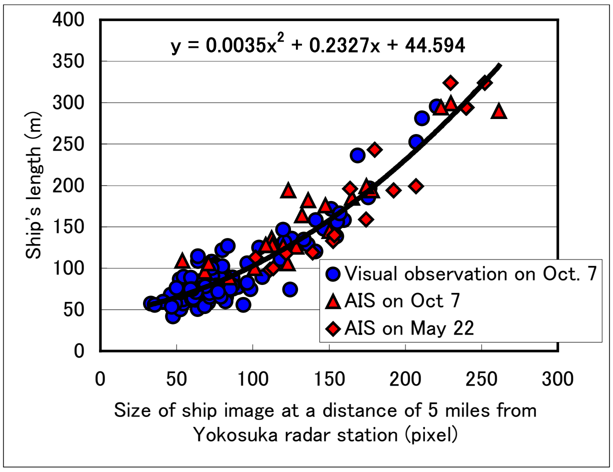

Fig.11 Ship's length versus size of ship image at a distance of 5 miles from Yokosuka radar station

3.3 Judgment of the Risk of Collision

In order to judge the risk of collision in the vessel traffic analysis, SJ (Subjective Judgment) value and Bumper Model are used. The SJ value means 'subjective risk of collision felt by a watch officer against target ship' obtained by ship maneuvering simulator experiments, and is calculated by the following formulae.

(i) Crossing encounter:
  own ship is give-way: $SJ = 6.00X + 0.09R' - 2.32$
  own ship is stand-on: $SJ = 7.01X + 0.08R' - 1.53$
(ii) Head-on encounter: $SJ = 6.00X + 0.09R' - 2.32$
(iii) Overtaking encounter:

$$SJ = 54.43X + 0.24R' + 2.77dR'/dt - 0.784$$

where

$X = |dD/dt|\, L_O/V_O$: non-dimensional change rate of target ship direction
$R' = R/\{(L_O+L_T)/2\}$: non-dimensional distance between own ship and target ship
$dR'/dt = V_R/V_O$: non-dimensional relative speed between own ship and target ship
dD/dt : change rate of target ship direction (rad/min)
L_O : length of own ship (m)
L_T : length of target ship (m)
V_O : speed of own ship (m/min)
V_R : relative speed between own ship and target ship (m/min)
R : distance between own ship and target ship (m)

In ship maneuvering simulator experiments, SJ value ranges from +3 (very safe) to -3 (very dangerous). In congested waters like Tokyo Bay, the ship encounter is regarded as dangerous when SJ value of one ship is less than -1.

In the Bumper Model, it is assumed that each ship is navigating with a bumper around the ship, and if the bumpers of two ships overlap, these two ships have a risk of collision. In general, the shape of bumper is semiellipse having semimajor axis of 6.4 L and semiminor axis of 1.6 L in the front side of a ship, and semicircle having radius of 1.6 L in the rear side of a ship, where L is length of the ship. In our vessel traffic analysis, the shape of bumper is approximated by rectangle as shown in Fig.12, and when the bumpers of own ship and target ship overlap, encounter is regarded as dangerous.

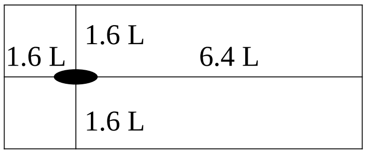

Fig.12 Rectangular bumper used for judgment of the risk of collision

4. Vessel Traffic Characteristics in Tokyo Bay

4.1 Analysis of Vessel Traffic Congestion with L-converted Ship's Density Distribution

All tracks of the ships observed by Yokosuka and Kawasaki radar stations in the period from 00:00 to 23:59 on 27 May, 2004 are shown in Fig.13.

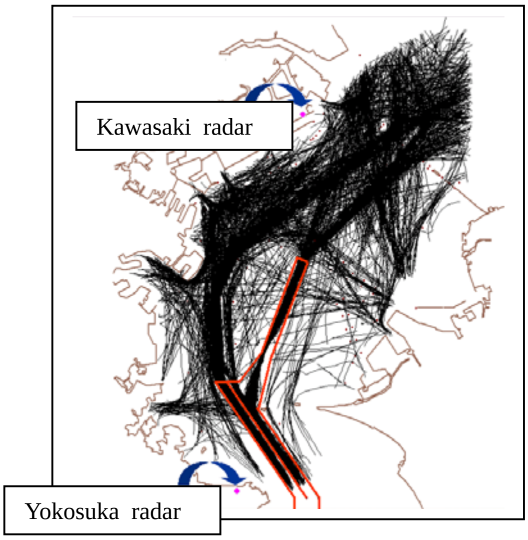

Fig.13 All tracks of the ships (00:00-23:59, 27 May, 2004)

In order to know the vessel traffic congestion, L-converted ship's density distribution has been often used. The L-converted ship's density represents the number of ships per unit area taking into account the length of the ship. A ship of length L (m) is counted as L/70 ships, where 70 (m) is the standard length of a ship; e.g. a ship of length 210 m is counted as 3 ships. Fig.14 shows L-converted ship's density distribution for the vessel traffic shown in Fig.13. The shading in each 500 m x 500 m mesh is proportional to the L-converted ship's density in that mesh. It can be seen from the figure that a large number of vessels navigated Uraga Suido Traffic Route and Naka-no-se Traffic Route. It is also found that many northbound vessels navigated from the exit of Naka-no-se Traffic Route and many southbound vessels navigated to the entrance of Uraga Suido Southbound Lane.

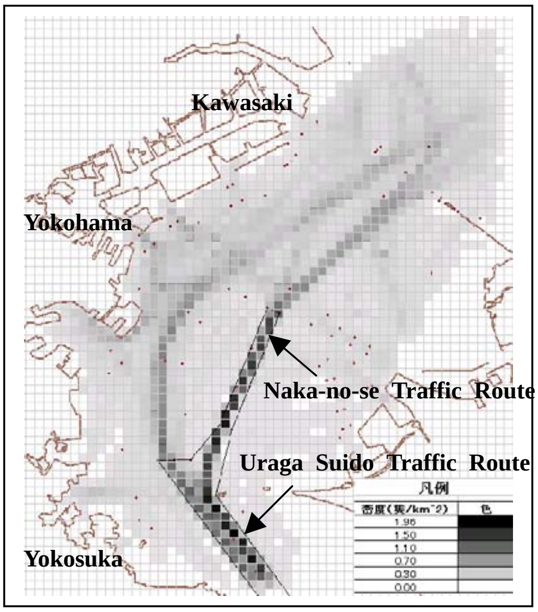

Fig.14 L-converted ship's density distribution (00:00-23:59, 27 May, 2004)

4.2 Analysis of Dangerous Encounters with SJ value and Bumper Model

Fig.15 shows the ships' positions of various dangerous encounters (SJ value less than -1 or bumper overlapping) during 05:00-09:00 on 27 May, 2004. If the bumpers of own ship and target ship overlap, both ships are indicated by blue squares. In dangerous encounters judged by SJ value, when the encounter is crossing, head-on and overtaking, both ships are indicated by green circles, red crosses and brown triangles, respectively. It is clear that in Naka-no-se Traffic Route and Uraga Suido Northbound Lane, there were many dangerous ships judged by Bumper Model because many ships navigated in the same direction with short gaps. In the area off Yokohama, as the ships entering Yokohama area met the southbound ships from Tokyo area, there were many dangerous crossing encounters judged by SJ value.

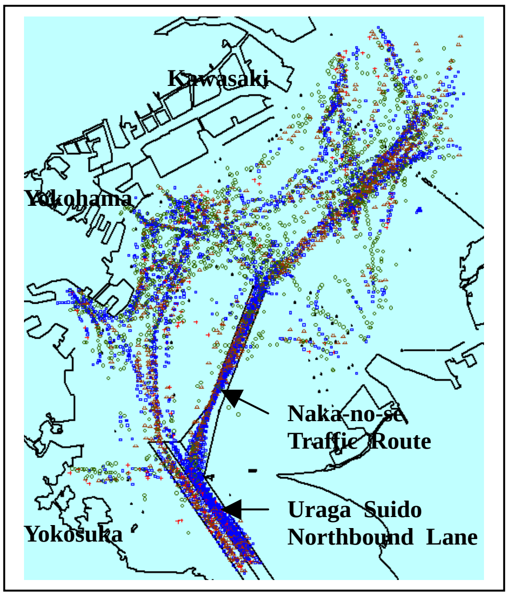

Fig.15 Ships' positions of dangerous encounters during 05:00-09:00 on 27 May, 2004

The ships' positions of dangerous encounters during 16:00-20:00 on 27 May, 2004 are shown in Fig.16. It can be seen that in the west of Naka-no-se and Uraga Suido Southbound Lane, there were many dangerous ships judged by Bumper Model, and the dangerous crossing encounters were also dominant off Yokohama and Kawasaki.

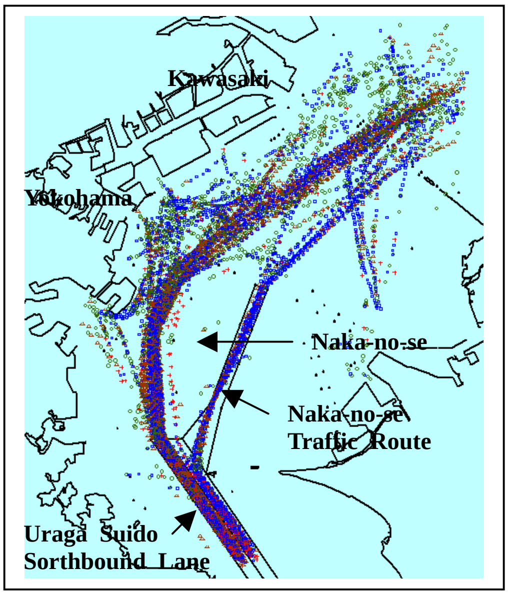

Fig.16 Ships' positions of dangerous encounters during 16:00-20:00 on 27 May, 2004

5. Conclusions

This study described the development of remote radar/AIS network system for observing vessel traffic in Tokyo Bay. The system configuration was shown and the newly developed radar/AIS web site was introduced. Then various functions of software to analyze vessel traffic such as 'moving image', 'superposing display', 'plotting', 'automatic tracking', and 'automatic tracking using AIS information' were explained. The method to estimate ship's length from the size of ship image on radar screen as well as the methods to judge the risk of collision were also described. Finally, the analysis of vessel traffic congestion with L-converted ship's density distribution and the analysis of dangerous encounters with SJ value and Bumper Model were given. For the further study, long-term vessel traffic observation covering wide area of Tokyo Bay will be carried out using two radars and AIS, and the vessel traffic characteristics will be thoroughly investigated. For analyzing a huge amount of observation data, automatic tracking function has to be improved.

References

1. R. Shoji, H. Hagiwara, K. Ohtsu, S. Hayashi and H. Namie, "Study on Radar Network System for Observing Vessel Traffic in Tokyo Bay", *The Journal of Japan Institute of Navigation*, Vol.109, September 2003, pp.69-78.
2. S. Liu, T. Okano, H. Hagiwara, R. Shoji, H. Tamaru and K. Ohtsu, "Study on Radar Network System for Observing Vessel Traffic in Tokyo Bay - II. - Installation of Kawasaki Radar Station and AIS Receiving Station -", *The Journal of Japan Institute of Navigation*, Vol.111, September 2004, pp.225-233.