An Effective Presentation of Navigation Information for Prevention of Maritime Disaster Using AIS and 3D-GIS

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Abstract — **We present a method for communicating navigation information that will assist operators to prevent maritime disaster. Although this topic has been extensively researched, the navigational situation of vessels has received little attention. However, such a navigational situation is essential for understanding water bodies and ensuring maritime safety. To provide effective navigation information, this study first analyzes the actual situation of vessel traffic using Automatic Identification System (AIS) data. Operators can be based on the analysis to understand the trend of navigation ships in water bodies as an important reference. From the results of the analysis, we constructed a representable navigational information system. Different information was unified on a Geographical Information System (GIS) in two- and three-dimensional formats. The system was demonstrated in a navigation simulation of a real voyage ship in Osaka Bay, Japan. The integrated information can be comprehensively and realistically interpreted by operators. Therefore, the system is expected to effectively avoid maritime disaster.**

Keywords—AIS data; 3D GIS; Maritime traffic; Voyage simulation; Maritime disaster

I. INTRODUCTION

The rapid development of the world economy in recent years has been accompanied by increasing global movement of goods and materials. The vessels responsible for mass transportation of these goods are increasing in both size and number. Consequently, vessel congestion and accidents in main ocean transport routes are now frequent. As the number of vessels increases, the risk of marine accidents becomes ever higher. Most of these maritime accidents occur in narrow channels and coastal waters where the ships are crowded [1]. Most ship operators lack the advanced navigation technology and extensive navigation experience to negotiate such risky ocean areas. This situation is especially dangerous for ship operators with immature navigation experience because the danger is compounded by stress. Therefore, the provision of navigational information has become timely and important. Over the past years, several studies have focused on the presentation of navigational information. However, little attention has been devoted to the actual navigational situation of vessels, which is essential for understanding water bodies and ensuring maritime safety. Furthermore, in most studies, the navigational information is presented as two-dimensional images, which may not be easily interpreted by inexperienced operators. Therefore, this research proposes a novel method for presenting navigational information based on a two- and three-dimensional geographic information system (GIS) [2]. We also analyzed the actual situation of vessel traffic by using an Automatic Identification System (AIS), which provides sufficient navigational information to avert maritime disaster.

Maritime navigators usually acquire information from items such as paper charts, electronic charts, and radar. To safely reach his destination, a navigation officer accessing these sources must rely on his own judgment. However, the received information navigational situation alters in time and space, and requires continual reassessment by the navigator. Because it is processed by human thought, this information cannot be shared without the risk of ambiguous interpretation. On the other hand, unambiguous information is provided by GIS. Because GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information, it is eminently suitable for presenting navigational information [3]. In addition, operators can acquire positional information on nearby ships as well as their own ship by combining the AIS data and unifying them on GIS. In this way, the operators can comprehensively understand the compiled information. Moreover, because GIS can display information in three dimensions, it offers a more realistic portrayal of the situation in a specific ocean area. In this study, a voyage simulation was constructed that reproduces a real-time situation, enabling less experienced or foreign navigators to understand risk situations. This study is organized as follows. The following section analyzes the actual navigational situation of vessels. In Section III, navigational simulations are performed using a real voyage ship. The developed system will give an operator a greater sense of security during sea travel. The study concludes with Section IV.

II. ANALYSIS OF ACTUAL SITUATION OF VESSEL TRAFFIC IN OSAKA BAY USING AIS DATA

Here we analyze vessel traffic and the navigational status of ships in Osaka Bay, Japan (34°15'46.8"N~34°45'57.6"N;

134°49'30"E~135°40'48"E). The vessel traffic analysis is based on AIS data. The AIS technology automatically provides information that can help avoid collisions. SOLAS (The International Convention for the Safety of Life At Sea) stipulates that AIS be installed aboard all international voyaging ships of 300 gross tonnage (GT) and all noninternational voyaging ships exceeding 500 gross tonnage. AIS transponders utilize VHF (Very High Frequency) frequencies [4], over which information related to the piloted vessel and other vessels can be transmitted; this information includes dynamic, static, and voyage-related data from several vessels. The information supplied by AIS data is detailed in Table 1. In this study, these data are used to analyze and present the situation of vessel traffic in Osaka Bay.

A. Statistical analysis of the passage of ships in Akashi Strait and Tomogashima Channel using AIS data

This study analyzes the vessel traffic in Osaka Bay, located in the east exit of the Seto Inland Sea, Japan. A map of Osaka Bay and the ocean area investigated in this research is shown in Fig. 1. Because Osaka Bay contains two Japanese international trade ports, namely the Kobe port and Osaka port, the area is frequently crowded with large ships. Osaka Bay also contains two traffic exits—Akashi Strait and Tomogashima Channel located in the western and southern parts of Osaka Bay, respectively. These portals direct ship traffic into and out of Osaka Bay.

Table 1. The contents of AIS data

Data Category	Contents
Dynamic data	Ship's position, universal time coordinated, speed over ground, course over ground, heading, navigational status, etc.
Static data	MMSI (Vessel's Maritime Mobile Service Identity) number, IMO (International Maritime Organization) number, call sign, ship name, type of ship, length and breadth
Voyage-related data	Draught, hazardous, cargo type, destination, and ETA (Estimated time of arrival) etc.

The AIS data were acquired at the Faculty of Maritime Sciences, Kobe University, Japan, on March 7, 2012. We compiled statistics on vessel traffic and cargo type of every MMSI ship number. These data revealed two main categories of ships in Osaka Bay: cargo and tanker. Of the 333 ships observed in Osaka Bay on March 7, 2012, 196 and 82 were cargo and tanker ships, respectively. The pie graph in Fig. 2 shows the ship categories occupying Osaka Bay and their percentage contribution to the traffic.

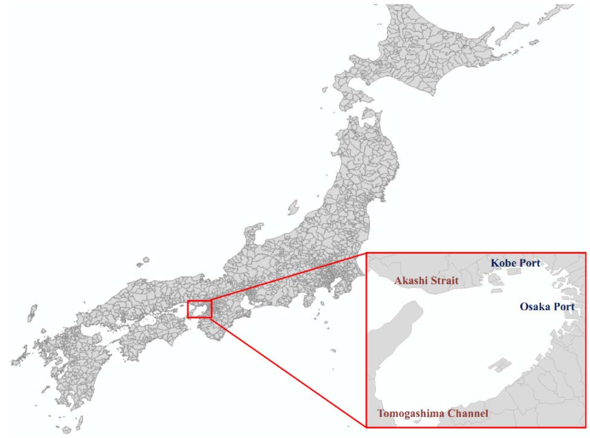

Fig. 1 Research target area (Osaka Bay)

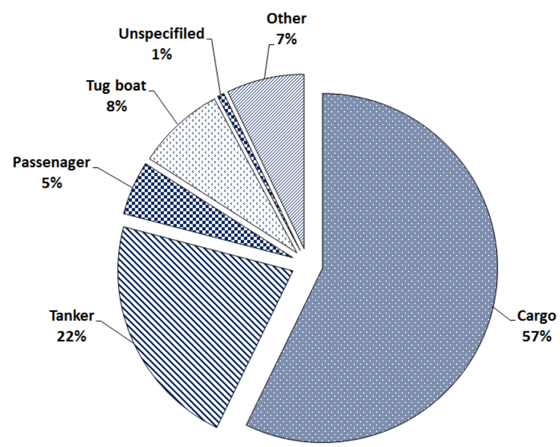

Fig. 2 Types of vessels operating in Osaka Bay on March 7, 2012

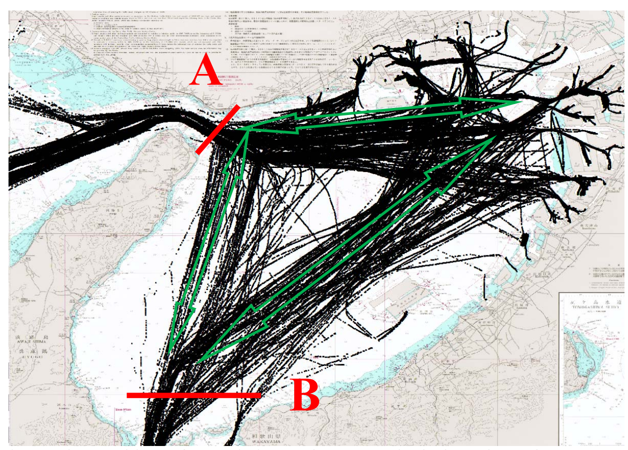

Fig. 3 The tracking of vessels in Osaka Bay. Black dots show the routes of individual vessels and the green arrows show the general trend of movement. A and B indicate the Akashi Strait and Tomogashima Channel, respectively.

Fig. 3 tracks the movement of all vessels in Osaka Bay on March 7, 2012. In this figure, the black dots indicate ships tracked by AIS data. From this analysis, we observe that most ships residing in Osaka Bay pass through the Akashi Strait route or Tomogashima Channel, entering the Osaka port or Kobe port, and some ships operate between the two portals. The major routes are delineated by green arrows in the figure. The routes adopt a distinct triangular pattern.

As the first step in our analysis, we elucidated the situation of ships passing through Akashi Strait and

Tomogashima Channel in Osaka Bay from the AIS data. To this end, we performed a statistical analysis of ships arriving and departing via both routes, which is indicated respectively by the lines A and B in Fig. 3.

Fig. 4 is a bar graph displaying the number and categories of ships entering and departing Osaka Bay via Akashi Strait on March 7, 2012. This figure confirms that more ships pass in and out of Osaka Bay in the afternoon than in the morning. Very few tankers departed Osaka Bay via Akashi Strait in the early morning; however, the flow of tankers sharply increased at 4:00. At the same time, other types of ships passed though Akashi Strait, leading to a heavy traffic flow. From 11:00, the traffic volume gradually increased, peaking between 17:00 and 19:00. Significantly large number of tankers passed Akashi Strait during the afternoon hours.

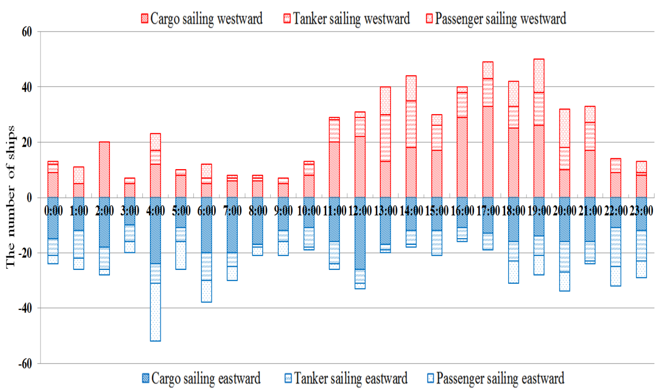

Fig. 4 The number and categories of ships operating in the Akashi Strait

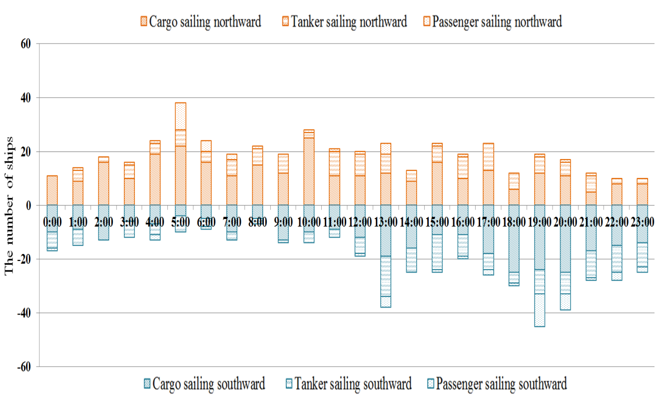

Fig. 5 The number and categories of ships operating in the Tomogashima Channel

A similar analysis of the traffic flow in the Tomogashima Channel was undertaken. The results are shown in Fig. 5. According to the statistics, most of the ships entering Osaka Bay though Tomogashima channel between 4:00 and 6:00 were cargo ships. The number of ships departing Tomogashima Channel increased in the afternoon, and peaked at 19:00. Many tankers used the Tomogashima Channel in the morning, and a large number of ships accumulated in the water body.

These analyses reveal that the majority of ships operating in Osaka Bay pass through Akashi Strait and Tomogashima Channel [5]. To reduce the risk of accident, we must identify the congestion area of the ships operating in the bay. Thus, we next analyzed the congestion situation of ships in wide water bodies.

B. Analysis of the congestion situation of ships in Osaka Bay

In this subsection, we analyze the congestion situation of ships by their density distribution. The region was divided into grid areas of 5 km × 5 km. Then according to the ship positions, a sea area is divided into different regions, each of which is individually studied. We calculated the number of ships passing through every grid within the investigation period. Because the AIS data are not homogeneously transmitted over the region, we interpolated the position data on a per-second basis. As an example, Fig. 6 shows the distribution of ships navigating Osaka Bay between 4:00 and 9:00 in the morning.

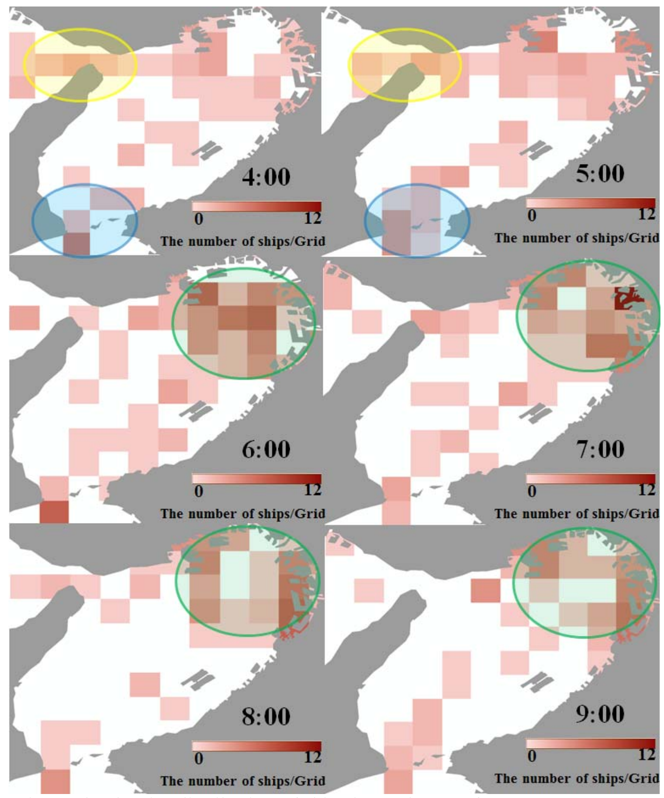

Fig. 6 The density distribution of ships in Osaka Bay from 4:00 am to 9:00 am. High and low traffic density is color coded red and white, respectively.

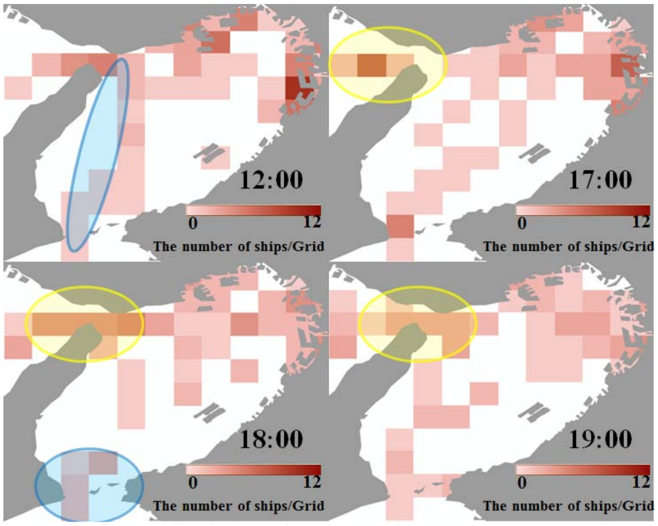

Fig. 7 The density distribution of Osaka Bay from 12:00 to 19:00. High and low traffic density is color coded red and white, respectively. Yellow and blue ellipses enclose the Akashi Strait and the Tomogashima Channel, respectively.

This analysis agrees with that of the previous section, in which ships were shown to be crowded around the Akashi Strait and Tomogashima Channel. Especially, traffic flow through both portals increased at 4:00, and was established in the harbor by 5:00. In addition, ships began to anchor outside the Kobe and Osaka ports at 6:00. Clearly, the anchored ships were scheduled to enter the port in compliance with port working hours. At 8:00 to 9:00, when the ships were prepared to unload their cargo, the traffic density of near the port suddenly increased. In accordance with economic action, the congested areas altered from the main traffic route to both ports throughout the morning.

Fig. 7 shows the traffic density distribution at mid-day and in the evening (between 17:00 and 19:00). At 12:00, many ships passed between Akashi Strait and Tomogashima Channel. Throughout the evening, the congested areas gradually altered from the harbor to the main traffic route, as the unloaded ships departed their respective ports and followed the route. For this reason, the ship volume was increased in the Akashi Strait and the Tomogashima Channel.

From the above vessel traffic analysis, we can elucidate the navigational situation of ships in Osaka Bay. In particular, the navigational trend of various ship categories becomes clear. Moreover, we analyzed the congestion situation in the wide ocean area in terms of the density distribution. The congestion area is temporally dynamic and reflects the business hours of harbor facilities. If a ship operator understands the congestion situation beforehand, he can perform operation in a safer manner.

Next, we integrated these results into a navigational information system accessible to operators navigating in the narrow water bodies of Osaka Bay.

III. NAVIGATIONAL SIMULATION OF REAL VOYAGE SHIP IN OSAKA BAY

To avert maritime disasters, we construct a navigational information system in a three-dimensional format. Because the human brain perceives objects in three dimensions, presenting the information in this way can render a situation more recognizable than a two-dimensional display. The presented information included three-dimensional water depth, detailed information of beacon location, and the navigational situation of other ships. In this section, we simulate a real voyage ship navigating the Osaka Bay on the basis of AIS data. This simulation system provides ship operators with pre-voyage navigation and training. Moreover, because AIS is installed in the system, the navigational route of the ship is recorded during the voyage. Thus, ship operators can also use the simulation to reproduce and review their voyage.

The simulation was validated on a large container ship because these liners are regular visitors to the maritime area. The test ship is an international voyaging ship operated by foreigners. According to the AIS data, the test ship navigated from the Seto Inland Sea, destined for Osaka port at 7:00. The test ship passed through Akashi Port at 4:00, the time of peak morning traffic flow. The dense traffic situation is unsettling to foreign and inexperienced operators. To solve this problem, we provided the ship sailing in the narrow waters with three-dimensional navigational information, from which the operators could effectively understand the traffic convergence conditions and navigational environment. The principal characteristics of the test vessel are listed in Table 2.

Table 2 Principal aspects of the test vessel

Item	The test vessel
Vessel' type	Container ship
Overall length (m)	148
Overall width (m)	24
Draft (m)	8
Weight (ton)	9957
Max. speed (knot)	14

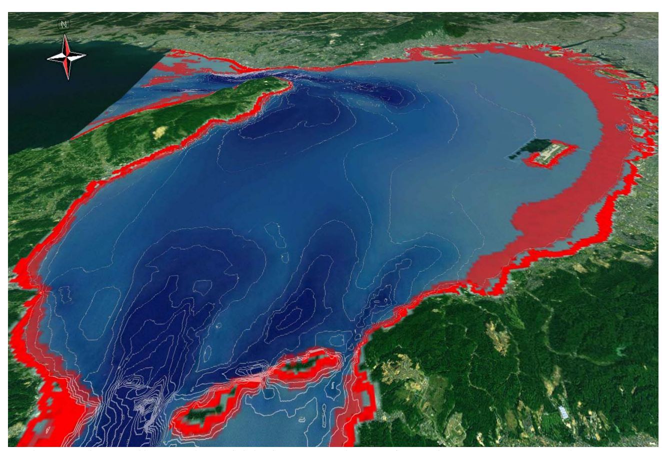
Fig. 8 Three-dimensional bird's-eye view of Osaka Bay. Increasing water depth indicated by darker shades of blue.

A bird's-eye view of Osaka Bay is shown in Fig. 8. The land and the ocean parts are separately displayed. From this figure, we can easily understand the nature of the sea bottom; for example, the eastern part of Osaka Bay is shallow and relatively flat, whereas the western part gradually deepens. Therefore, a ship cruising through narrow waters, such as Akashi Strait in Osaka Bay, can obtain immediate knowledge of the water depth situation. For easy interpretation, the proposed system provides the contour lines of water depth (the white lines in Fig. 8). Risky cruising areas are also provided. Red regions indicate areas in which a test ship of 8-m depth or more cannot sail. The water depth contours in conventional charts are too coarse for easy recognition of local water depth. By three-dimensional seabed topography, the complex rises and dips in the seabed can be more clearly envisaged.

Fig. 9 shows an example of the integrated display of the ship situation and the dangerous areas in Osaka Bay at 4:00 on March 7, 2012. Ships in the vicinity and their directions, extracted from AIS data, are indicated by arrows. The test ship is encircled, and the surrounding ships are colored according to their cargo type. At this moment, ships are concentrated near the test ship in the Akashi Strait route (the yellow rectangle area in Fig. 9), while many tankers are anchored outside the Osaka port (the green rectangle area in Fig. 9). The proposed method is easily used in a real-life situation to identify the positions of ships in the entire sea area. As indicated in Fig. 9, different information can be rendered absolutely clear and explicit. The chart as a well-known navigational tool for ship operators, also can be combined into this system, operators can confirm the navigational information while checking the chart.

Fig. 10 shows the voyage simulation of the ship operator's view. This three-dimensional simulation reproduces the actual action of the test ship. The operator observes a loaded oil tanker passing through Akashi Strait, and desires to maintain a safe distance. The dangerous areas near the draft of the test vessel, which should be strictly avoided, are highlighted in red. By noting this dangerous area, the ship can avoid becoming grounded.

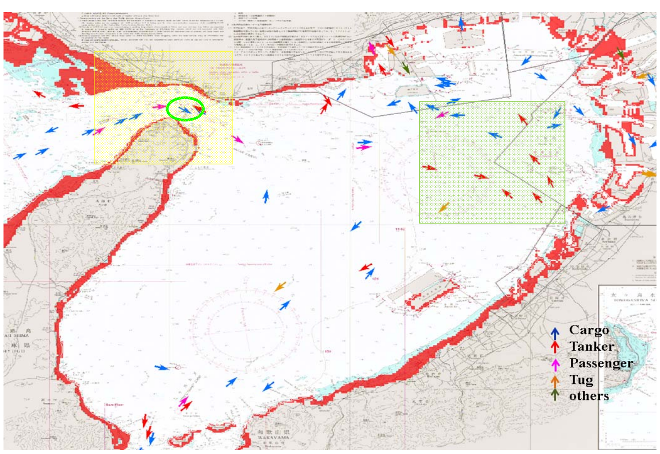

Fig. 9 The navigational situation of ship, indicating the dangerous area (4:00 AM, March 7, 2012). The test ship is encircled.

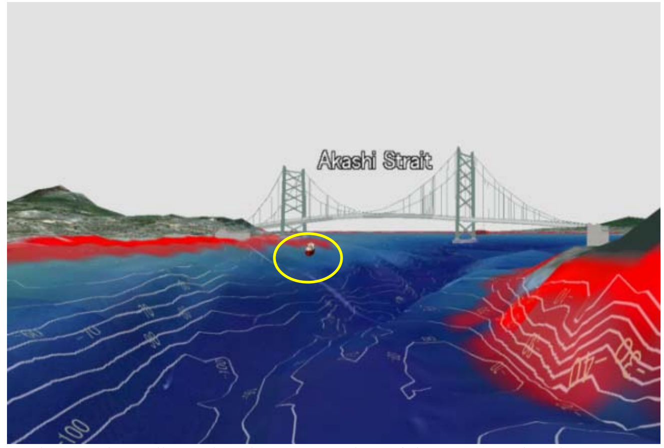

Fig. 10 Three-dimensional representation of the test vessel's view (4:00 AM, March 7, 2012). The encircled object is an oil tanker.

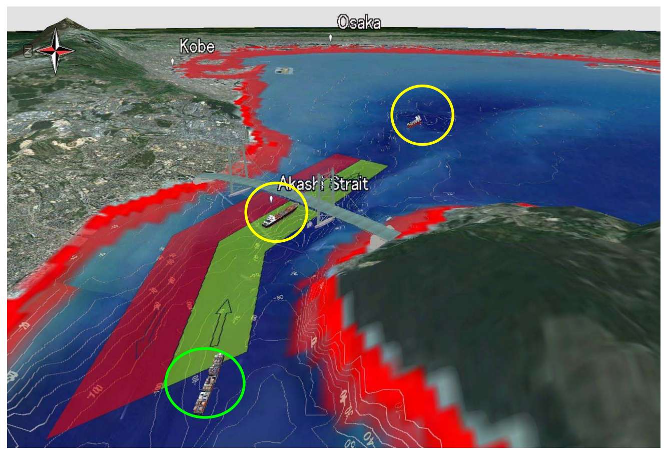

Fig. 11 A bird's-eye view of the test vessel (in the green circle) operating in Akashi Strait (4:00AM, March 7, 2012). The ship is traveling in the direction of the green band; the opposing direction is red.

This system also has a free viewpoint function, which can assist the operator to elucidate the water depth at his current position. In particular, the three-dimensional display can portray potentially harmful geographical features directly beneath the ship. Moreover, because other information such as detailed water depth contours and the submarine geology are also included, a very effective integrated information tool is realized.

Fig. 11 is an example of a changing viewpoint. This figure shows the navigational situation of ships operating in Akashi Strait. Our system permits, for the first time, an objective view of a self-cruising situation. This visual understanding is especially useful in Akashi Strait, wherein a large number of ships sail through a narrow route. In current navigation systems, operators obtain the positions of nearby ships from radar images. Extracting this information requires extensive knowledge of the operator. By virtue of its three-dimensional format, the proposed system offers an intuitive understanding of the situation of the water body and the positions of ships in the vicinity.

Other information can be combined into the system. For example, in Fig. 11, the direction of travel and its opposing direction are indicated in different colors.

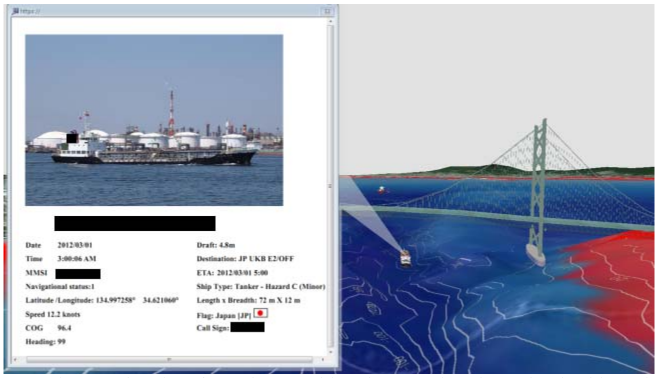

Fig. 12 The view from the test ship when passing through Akashi Strait

The operator's work could be reduced by displaying features such as buoys and lighthouses that guide him to his destination. In this system, clicking an object on the screen will display pertinent information. Fig. 12 shows an information display that appears when an operator clicks on the oil tanker navigating ahead of the test vessel. By following the link, the operator can access the AIS data. Furthermore, the operator can search for a landmark on the ship's bridge by referring to the photograph of the light beacon contained in the data. All of this information can be instantaneously accessed by a mouse click, which is less troublesome to the navigational officer's watch than book research. Therefore, we expect that our proposed system will improve the efficiency and safety of maritime navigation.

IV. CONCLUSIONS

This paper presents an important reference study of a ship navigating through Osaka Bay. The analysis demonstrates that navigation information can be effectively conveyed to ship operators. Moreover, from the results of our analysis, we constructed a representable navigational information system.

We proposed navigational studies using data from AIS and GIS that will reduce the risk of maritime accidents. The system conveys navigational information in the form of two- and three-dimensional images, which cannot be obtained from present navigation systems such as charts and radar images. The proposed system offers an intuitive and straightforward means of assessing the navigational situation. By unifying AIS data, it also admits the cruise situations of nearby vessels, enabling users to recognize a detailed ocean area situation containing marine traffic. Accordingly, this navigational system can contribute to individual vessel safety and assist in directing maritime traffic. In future studies, we will provide three-dimensional navigation information using AIS in real-time. By interpreting such real-time information, maritime disasters such as stranding and collisions can be prevented.

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