Sea Traffic Simulation and its Visualization in Multi-PC System

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Abstract: A real time sea traffic simulation is developed for a multi-PC system. The simulation is based on the field observation of the traffic, statistics on the sailing ships; ship species, numbers, origins, destinations and paths. Each ship is dealt with as an agent, and its motion is controlled along each respective passage plan. The simulated sea area is divided into sub-areas in an appropriate mesh size. Ship identities included in each sub-area are listed in a respective array. The list enables not only traffic control within each sub-area but also visual image from a selected ship bridge on multi-PC monitors. This simulation is applied to the evaluation of a high-speed navigation within a highly congested sea area, Tokyo Bay. In the simulation, more than 200 ships at one time, and 2000 ships in total are sailing within Tokyo Bay. Around a selected ship called "the own ship", positions and velocity vectors of the sailing ships are summed up and broadcasted through Ethernet. Four image generating PCs receive those broadcasted data and provide a visual image from the bridge of the own ship as a view of 180 degrees in horizontal width. The synchronization of the simulated world in these PCs is realized with the latest time adoption method, that makes a simple and useful ship handling simulator. An advanced navigation support system based on the speech communication joins as one of the multi-PCs in this simulation and the usability and safety of the support system have been confirmed. The night simulation is also powerful for the evaluation of light aids to navigation. The results have been reflected on the actual design of the light aid systems by Japan Coast Guard.

Keywords: Sea traffic simulation; Multi-agent system; Multi-PC system; Visualization.

1. INTRODUCTION

Sea traffic becomes more important especially for energy saving in transportation domain. An easy construction system for a traffic simulation is essential for evaluation of the present sea traffic system and for designing an improved system using new technologies. A <u>sea</u> <u>tra</u>ffic <u>s</u>imulation (SEATRAS) contains various natural conditions and traffic conditions. These conditions should be easily installed in the simulation and be evaluated both through statistical analyses and through subjective ones of expert mariners. The visualization of the simulation is also essential for the latter evaluation of expert mariners. We also propose a multi-PC system for providing a bridge view of a selected ship on a multi-screen projection system.

We propose a multi-PC system for a sea traffic simulation, which includes environmental simulation, sea traffic simulation and communication among sailing ships and land support or service centers. The component PCs are connected by Ethernet, mainly with UDP broadcast. As a default setting, each sailing ship has its passage plan including waypoints with each estimated time of arrival and turning condition. Each ship included in the simulation can be substituted for an independent ship agent installed in another PC on the network. This paper shows a conceptual design of the simulation system and its principal functions. Some actual applications are explained in Section 4.

2. SEA TRAFFIC MODELING AS A MULTI-AGENT SYSTEM

A sea traffic system can be regarded as a multi-agent system. Sailing ships, vessel traffic services and environments work as autonomous agents. The resulting world represents an actual traffic on the specified sea area. Each ship on the specified sea area shares information about natural conditions and sea traffic as a result of summary of each ship action. Synchronization of the information is essential for the actual behavior of the traffic system. Each ship decides its action based on the shared information. In the decision-making process, an accuracy of the information varies according to the level of concern to the object. Each component, ship or natural condition, should, therefore, change its accuracy level in the traffic model. In the sea traffic simulation, it is an essential function to substitute the high accuracy level component for the default low accuracy level one.

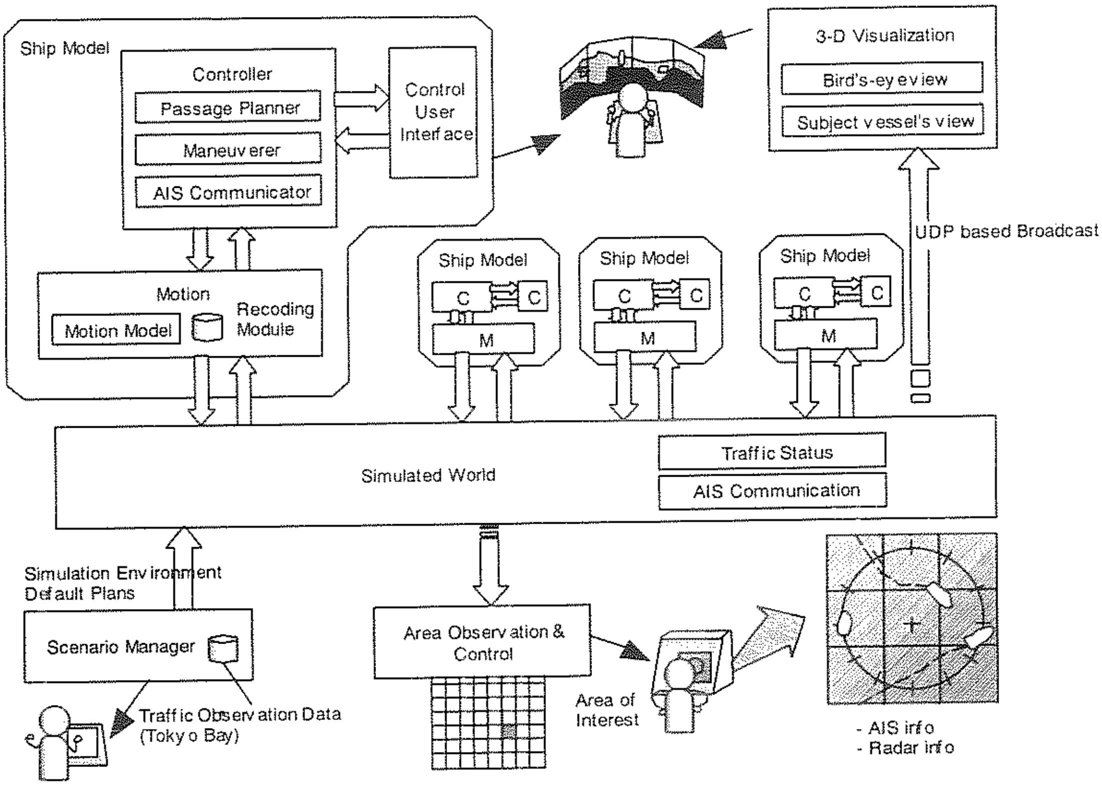


Figure 1. Architecture of Sea Traffic Simulation.

3. STRUCTURE AND COMPONENTS OF THE SIMULATION SYSTEM

3.1 Sea Traffic Simulation

We have developed a sea traffic simulation SEATRAS, which reproduces the ships' activities at a selected region of the sea, since 1985 [Numano, et al.. 1987]. It is composed of independent computational modules that control entities appearance, decisions, actions, and interactions with others. Figure 1 illustrates its architecture. The objects we defined are ship models, a simulated world, 3-D visualization systems, scenario managers, and area observation and control systems. In brief, a ship model is the representation of a ship. It is equipped with the mathematical motion models, controller modules, and control user interfaces. The simulated world manages the appearance of each agent, according to the pre-defined scenario, to satisfy the statistical feature of the real-world traffic phenomena. The 3-D visualization system exhibits a view from a selected ship. With synchronization to the ship model behaviors, it provides an interactive operation environment to a human operator. The area observation and control module provides an observation and control environment to the traffic controller. We have developed SEATRAS with an object-oriented design and a distributed implementation. Thus the whole system has fault tolerance and the individual modules have flexibility of development and improvement.

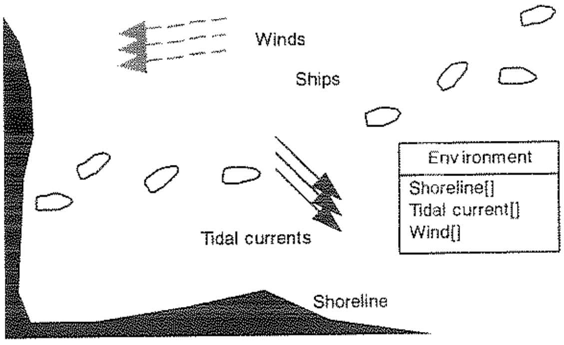


Figure 2. Environment Representation.

3.2 Environment Representation

The operators of the ships take relevant information to the navigation into consideration when they make any decision. Thus we first give a representation for the natural resources that have effects on navigation. Among many physical and psychical effectors, the geographical conditions, tidal currents, and wind conditions are said to be the most major facts for the ship operators. As shown in Figure 2, we modeled a region of the sea by representing a set of geographical conditions, tidal currents, and winds. To define the default simulation environment, SEATRAS provides a scenario manger to edit the geographical settings, as well as it provides a default data set. The data set contains actual shoreline data, which was generated from the electronic navigation chart. Tidal current data based on the observation of the Japan Coast Guard is also available. The current version does not include any actual wind data.

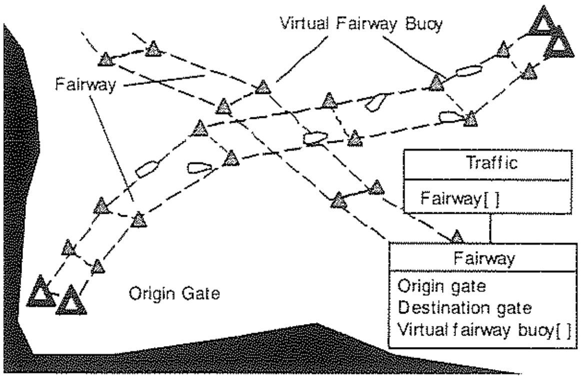


Figure 3. Traffic Representation.

3.3 Traffic Representation

A central issue on designing SEATRAS concerns the balance between statistical accuracy of area traffic and kinematical accuracy of individual ship motion. We decided to pursue the accuracy of area traffic in a level of number and distribution of the ships. Since any ship at the sea is located on the way between its origin and destination points, the distribution of the ships in a region, as a whole, has a certain trend according to their navigation objectives. Thus we introduce a concept "fairway" to represent a region with a probability of their existence there. As illustrated in Figure 3, a fairway is a virtual line with direction and breadth. It is represented as a sequence of a pair of virtual fairway buoys, which indicates the border of the line. The origin gate and the destination gate are special pairs of virtual fairway buoys, indicating ship agents' departure and arrival locations, respectively. At run time, the simulated world creates the agents as ship instances with the properties of arrival time, departure time, and arrival location as their passage plan to satisfy the given statistic data. SEATRAS provides a fairway data set that we generated from the statistical analysis of the traffic data, observed at Tokyo Bay in 1990, which is originally reported by the Ministry of Transport of Japan.

3.4 Ship Representation

To produce the behavior of each ship, we developed three subsystems to compose the ship model; motion, control and user interface. The motion subsystem simulates the motion of a ship based on built-in motion models. The control subsystem first percepts the current status of the ship and the surrounding environment including other ships, then takes an action to accomplish the passage plan, and change the plan if necessary. The user interface provides functions to edit the passage plans and operate the control system. SEATRAS also provides an autonomous passage planning module and maneuvering modules as default settings.

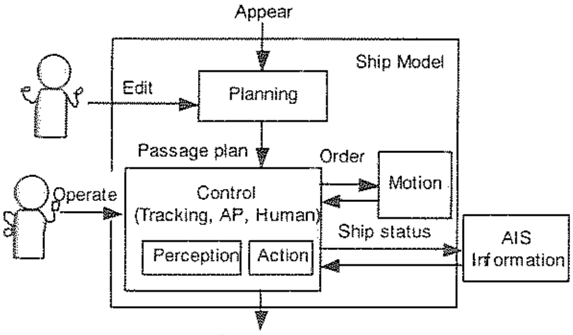


Figure 4. Components of the Ship Model.

3.5 Motion Models

The motion module simulates the motion of a ship based on the built-in motion models. It can be substituted any mathematical motion model. The current version of SEATRAS implements a simple response model (KT model [Nomoto, et al., 1956]), which is one of the most well known mathematical motion models, and we are currently implementing the precise MMG model [Ogawa, et al., 1977], based on hydrodynamic forces acting on a ship hull, into it.

3.6 Passage Plan Representation

The operators require the particular positions or areas to pass along in order to maneuver their ships. Thus they create a passage plan to satisfy the navigation objectives in advance of their departure. It includes the origin and destination points and the precise location and time at the waypoints. As shown in Figure 5, we model a passage plan as a sequential set of waypoints and rates of turn there. The origin and destination points are special waypoints that indicate the start and goal locations.

3.7 Passage Planning

Passage planner of SEATRAS makes passage plans, i.e. creates a sequence of waypoints from a set of the origin and destination points, using the statistical traffic data. From a given set of origin and destination points, it first selects a corresponding fairway, and then generates a certain internal division rate. Then it locates a sequence of points to divide the breadth of the selected fairway internally. Passage planner also provides a user interface to edit the plan without using the passage planner algorithms.

3.8 Maneuvering Module

The maneuvering module supports the maneuvering operation according to the navigation mode. There are three navigation modes in SEATRAS: manual, autopilot and tracking. When the manual mode is selected, a human operator needs to control the ship's direction and speed by hand. When the autopilot mode is selected, the autopilot module keeps the ship's direction automatically. A human operator needs to control its speed by

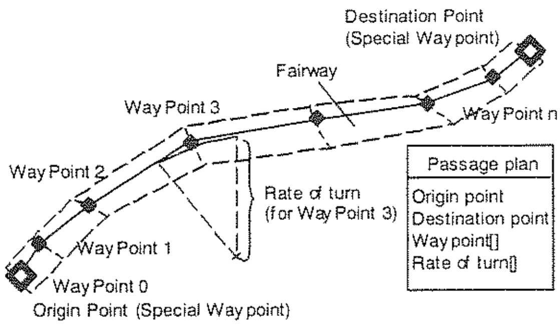


Figure 5. Passage Plan Representaion.

hand and to give the direction commands to the autopilot module. When the tracking mode is selected, the tracking module keeps its course automatically. With this mode, a human operator only needs to override this module's control. The module automatically calculates the objective direction to achieve the given plan and sends it to the tracking module as a direction command. SEATRAS creates a ship instance with a default configuration to use the tracking mode in a speed that satisfies the traffic statistics. For the users who operate a ship through the interactive operation environment, SEATRAS provides a control module to operate the selected ship, as shown in Figure 1, at manual or autopilot mode.

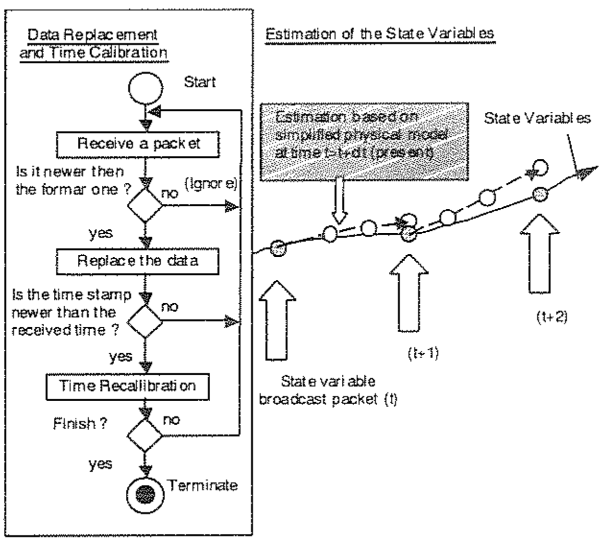


Figure 6. The Latest Time Adoption Algorithm.

3.9 Area Traffic as a Collection of the Motion

The motions of the ships form the sea traffic as a whole. To keep consistency with the statistical data, SEATRAS assigns a departure time, an origin and a destination points and a speed to each ship. At run time, each ship gets appeared at its origin point on the start time with the configurations, and starts and navigation. With this method, the current version of SEATRAS successfully reproduces the sea traffic at Tokyo Bay, a highly congested area with more than 200 sailing ships simultaneously.

3.10 Synchronization and Extrapolation Algorithm

In order to carry out real-time visualization, the scene and agents have to be remodeled smoothly. To address this issue, we have developed a synchronization and extrapolation algorithm LTA (Latest Time Adoption). This synchronizes with the control user interface in the ship model using the UDP based broadcast. The simulated world announces the status of the related ships and the environment around a selected "own ship", using the UDP broadcast. The 3-D visualization system is listening to the broadcast while the simulation, generates the new graphics, and redraws the scene as shown in Figure 6.

3.11 Traffic Observation and Area Control System

The area observation and control module of SEATRAS provides a means to recognize the traffic phenomena of the area of interest. When the user selects a certain area in the simulated world, it retrieves the ships in the area with their attributes. It is also equipped with a collision avoidance module that calculates the risk of the collision, modifies original passage plans of the respective ships, and sends the plans to them. This module enables us to develop and verify new collision avoidance algorithms. The module has an observation monitor to exhibit the ships with their attributes and passage plans. To simulate the condition of real-world observation, it filters the information according to the given configuration. Figure 8 is the snapshot of the monitor. It shows the view of simulated world while reproducing the traffic phenomena in Tokyo Bay. A short line with small ellipse represents the velocity, position and size of each ship.

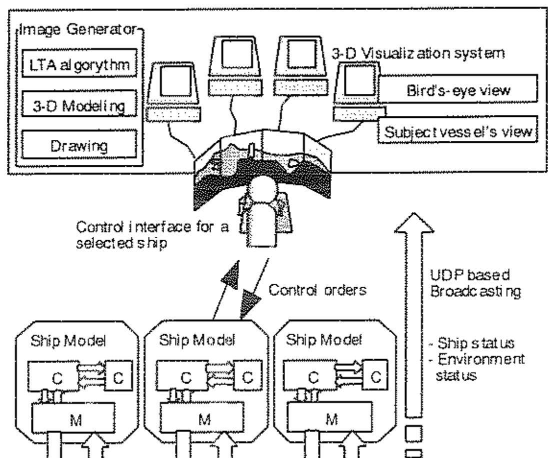


Figure 7. Visualization System Architecture.

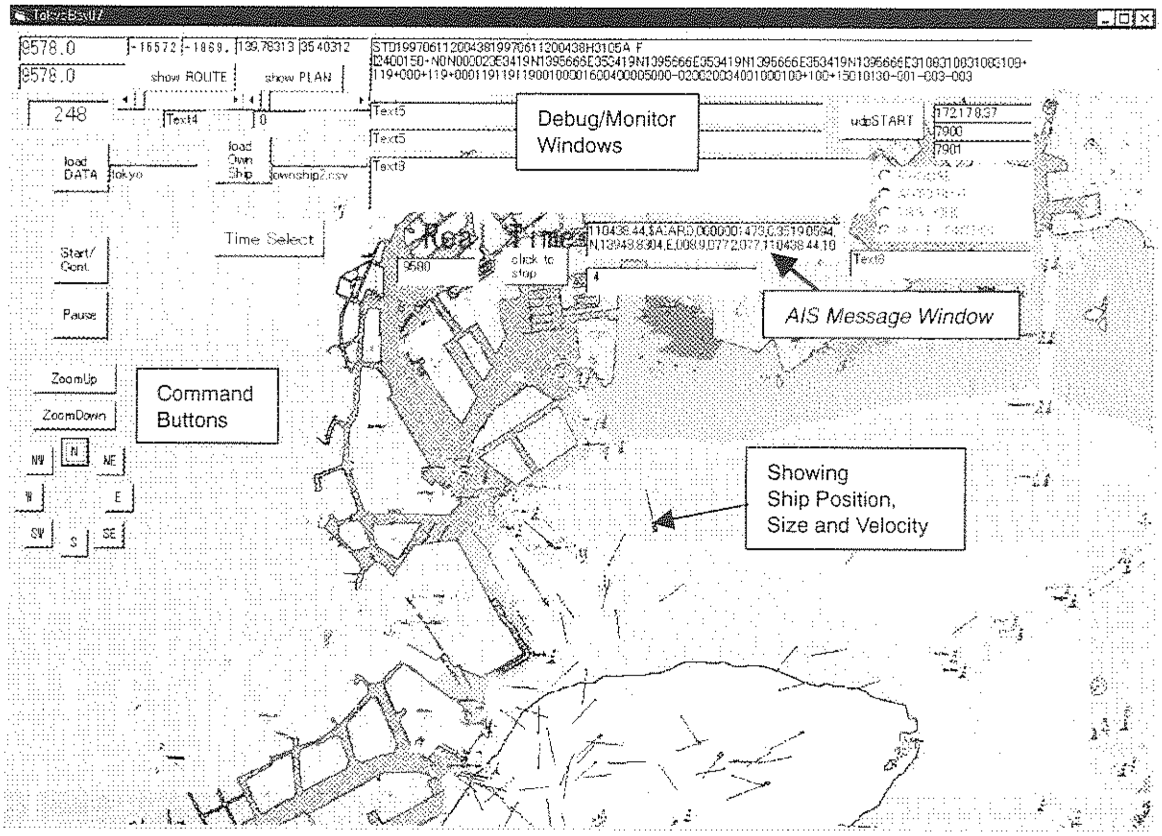


Figure 8. SEATRAS Monitor for Tokyo Bay with AIS Simulation

4. APPLICATIONS

4.1 Visualization for Ship Handling Simulator

Visualization is an important feature of the SEATRAS. As illustrated in Figure 7, the 3-D visualization system is composed of the image generator subsystems, which are distributed on four PCs. The subsystem is equipped with LTA extrapolation algorithm, 3-D modeling module, and drawing module.

4.2 Safety Assessment of High Speed Navigation in Highly Congested Sea Area

A national project aiming at constructing a large high speed cargo ship was been carried out. A half-size model was then constructed and tested under actual sea conditions. Safety navigation was also examined especially in a highly congested sea area. We have modeled Tokyo Bay as the highly congested sea area and examined effects of cruising speeds and support systems on the navigation safety. We indicated the possibility of the safety high speed navigation even in the highly congested sea area with the appropriate navigation support of crew and supporting apparatus. The high speed ship will be actually constructed as a ferry boat to connect desert islands with Tokyo.

4.3 Evaluation of Light Aids to Navigation

Various light aids to navigation such as buoys and light houses are easily represented in the visual system with strict physical models like brightness and blinking patterns. The design and improvement on the light aid system were checked with SEATRAS. Japan Coast Guard reflected the results of the simulation to the actual improvement. Figure 9 shows an example of the simulated image applied to Kurushima Strait.

4.4 Simulation Study on Utilization of AIS

In the present circumstances, operators of the ships at the sea are required to make decisions without exactly knowing the intentions of the other ships. As a result, a passage through a congested area is extremely difficult and needs careful attention. To address the issue of ambiguity, the International Maritime Organization (IMO) decided to bind all ships of 300 gross tonnage and upwards engaged on international voyages to be fitted with the Automatic Identification System (AIS) by the date of July 2002. The AIS is a system for communication among ships and land facilities, which is composed of communication devices, medium and message protocols. The device broadcasts and receives the communication packets to share the data with the ships that share the same region and land facilities in concern. The data include the sender's identification, ship's current status, and navigation intentions, e.g. destination point and

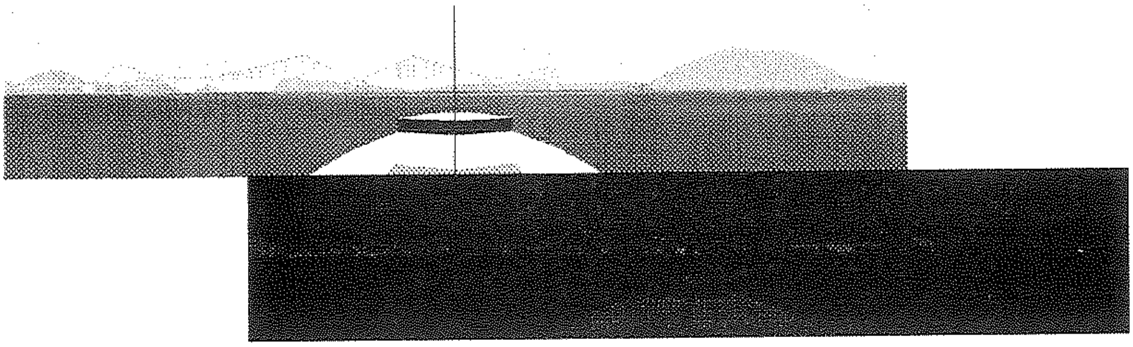
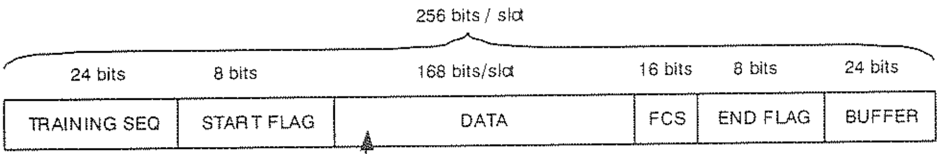


Figure 9. Visualized Image from Selected Ship Bridge(Kurushima Strait in Seto Inland Sea; day and night)



Message	Contents
Ship Static and Voyage related data	Message ID, User ID, IMO Number, Call Sign, Name, Type of ship & Cargo Type, Position of GNSS antenna, Type of Nav Sensor, ETA (Estimated Time of Arrival), Actual Draught, Destination (This message uses 2 slots)
Position Reports	Message ID, Data Terminal Ready, Data Indicator, User ID, Navigation Status, Rate of Turn, Speed Over Ground, Position Accuracy, Longitute, Latitude, Course Over Ground, Heading, Time stamp, Comm State (168 bits in total)

Figure 10. The Message Structure of the AIS Communication Packet.

passage plan. Figure 10 illustrates the communication packet format defined in the AIS. The AIS system enables the ships equipped with it to share their navigation goals and current status. Using the AIS information with the existing radar systems, we are currently developing a traffic observation system. The radar systems have an advantage in the ability to capture any objects in a certain region --they don't require the objects to be equipped with any special communication interface--, while they have a disadvantage that their information solely contains external features of the objects. In contrast with the radar systems, the AIS systems have an advantage that they are able to capture not only the external features of the targeted ships, but also internal features and attributes, such as names and destinations, of them. As an application, we are considering an extension of the communication module of SEATRAS. The extension detects the ships in its collision course and communicates to modify the plans to avoid collision, autonomously.

The AIS is expected to provide the similar information on the ships, as required for the area observation and control module that we described in 3.11, in the real world. Thus we have developed a communication module that simulates the AIS communication via UDP broadcasting on the Ethernet. The passage-planning module that collaboratively plans with other ships and the area control module are under development.

5. SUMMARY

We have constructed a multi-PC simulation system for various aspects to the sea traffic (SEATRAS). It realizes a flexible and robust function in a construction phase and an execution phase. SEATRAS is composed of environmental components and ship components in an object oriented manner. SEATRAS is constructed as a distributed PC system in which various component programs are running with sharing synchronized information. In the distributed PCs, a simple and powerful visual system is realized. An advanced navigation support system has been developed based on voice communications has been developed with the aid of SEATRAS, it was powerful for gathering expert mariners needs and evaluation of the support system. This system architecture can be applicable to any other large and complex system and enables effective designs and evaluations on it.

REFERENCES

Nomoto, K., K. Taguchi, K. Honda and S. Hirono; On the Steering Qualities of Ships (1), *J. of Naval Architects of Japan, Vol. 99, 1956.*

Numano, M.; Real Time Simulation System for Automatic Ship Navigation, *Proc. of 4th International Conference on Marine Simulation, pp. 350-358, 1987.*

Ogawa, A., T. Koyama, K. Kijima; MMG Reports - I, *Bulletin of the Society of Naval Architects of Japan, No. 575 (1977)*