Simulation Study on Sea Traffic Control at an Intersection Utilizing Information Sharing with Automatic Identification System (AIS)

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Abstract: Sea traffic is confined within a 2D sea surface. Although there inevitably exists an intersection, boundaries of the intersection are vague as a result of free sailing of vessels on the sea surface. The Global Positioning System (GPS) and the Automatic Identification System (AIS) are now in service and they enable mutual communication among vessels in passage about their positions and speeds with their identities. The AIS can also provide various binary messages for traffic control by the Vessel Traffic Service Center (VTS). The VTS, therefore, can provide effective information to vessels in passage to avoid collision danger and for the smooth and efficient sea transportation. The conventional VTS gathered sea traffic information with Radio Detecting and Ranging (RADAR) systems and voice communication through Very High Frequency (VHF). The AIS provides precise information about vessels within the objective sea area of the VTS. It is possible for the VTS to indicate much safer courses and speeds to vessels in passage based upon the precise information with the AIS. We have developed a sea traffic simulation system (SEATRAS) for maritime safety assessment and development/improvement on navigation support systems and aids to navigation. As the SEATRAS has already supported the AIS communications, it is ready to be used for the VTS simulation for checking algorithm of a sea traffic control. On the SEATRAS we define an intersection zone and four neighboring zones. The VTS agent is also joined to the SEATRAS to gather status information of vessels in these zones with the AIS. The VTS makes an optimal set of navigation plans and gives orders or recommendations for the optimal plans to the respective vessels. We perform a simulation study using the SEATRAS and investigate on the safety and the efficiency of the sea traffic around an intersection..

Keywords: Sea traffic simulation; Traffic control; Information sharing; Automatic identification system.

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 sea traffic simulation (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 comprises 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 User Datagram Protocol (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 brief explanation of the simulation system and its principal functions. As one of the functions of VTS, a traffic control at an intersection is explained in Section 4.

2. SEATRAS FOR VESSEL TRAFFIC SERVICE

A sea traffic system can be regarded as a multi-agent system. Sailing ships, vessel traffic services (VTS) 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.

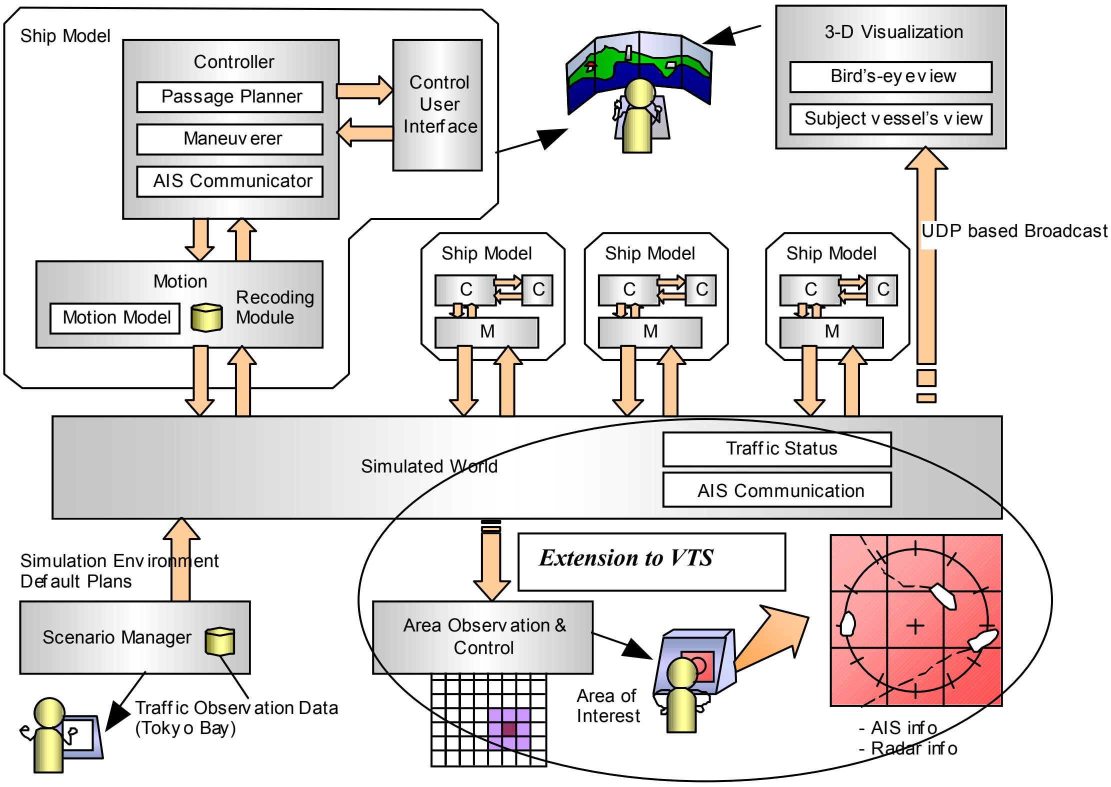


Figure 1 Architecture of Sea Traffic Simulation.

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. AIS communication can be simulated with message broadcasting through Ethernet.

3. SHIP REPRESENTATION

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 [Numano, et al. (2001)]. A ship model is the representation of a ship, which comprises a mathematical motion model, a controller module, a control user interface and a communication module. 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.

3.2 Traffic Representation

A central issue on designing SEATRAS concerns the balance between statistical accuracy of area traffic and kinematical accuracy of individual ship motion [Nomoto, et al. (1956) and Ogawa, et al. (1977)]. 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 2, 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

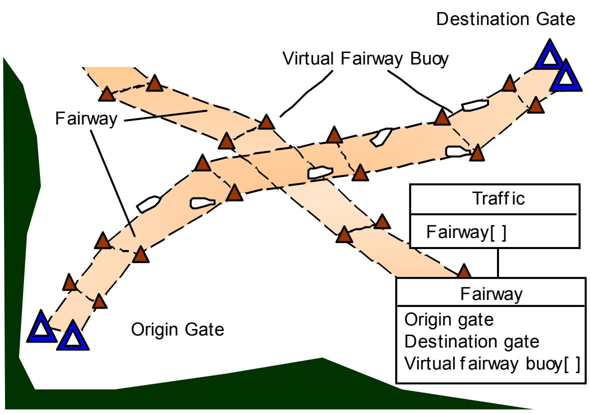


Figure 2. Traffic Representation.

of the traffic data, observed at Tokyo Bay in 1990, which is originally reported by the Ministry of Transport of Japan. There inevitably exist various types of intersections among virtual fairways. We can focus on a single intercourse and control each ship motion as a function of VTS.

gin 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. Intersection and its neighboring zones are set on the sea surface. Ship identities are collected within each zone. With the identities, a VTS module can gather information about the sailing ships within each zone through AIS communication.

3.4 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

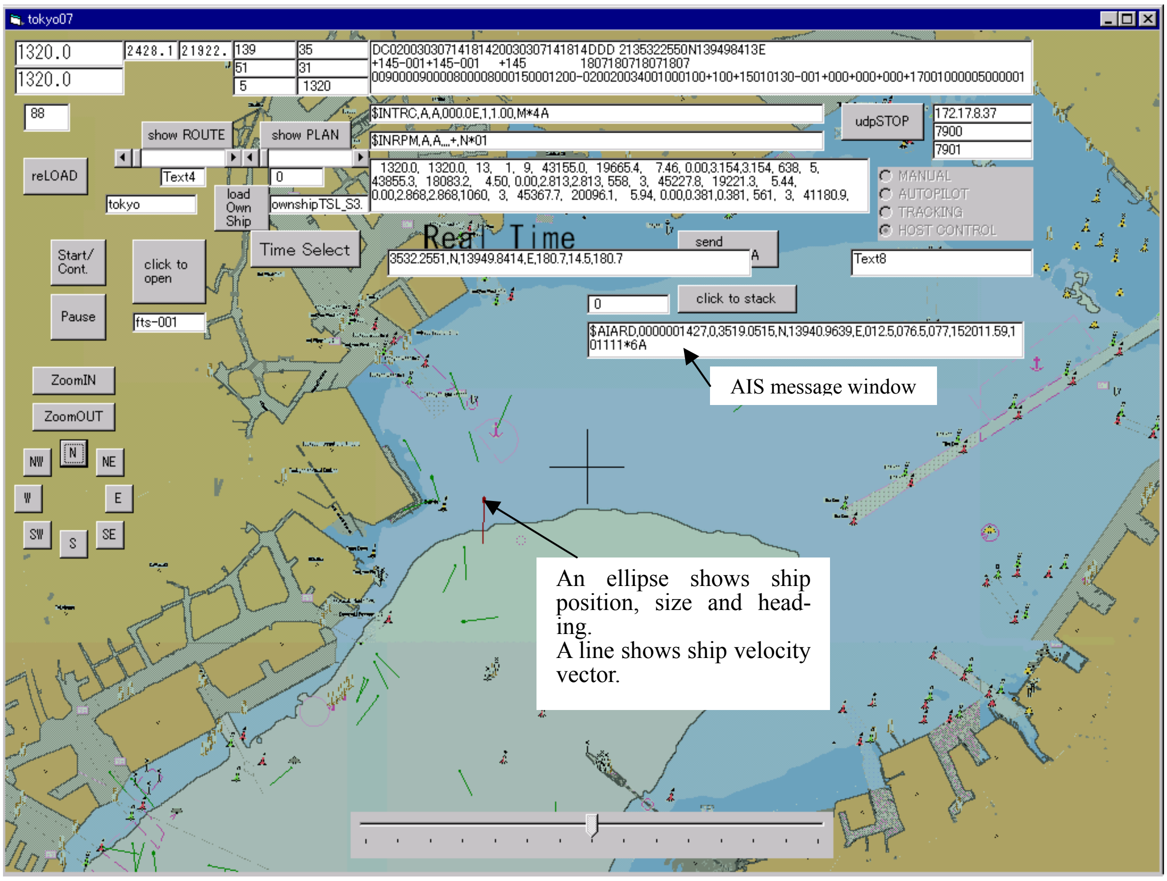


Figure 3. Snapshot of Simulation Monitor

3.3 Area Traffic as a Collection of the Ship 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 ori-

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. The UDP broadcast and the LTA algorithm enables easy extension to add various types of the agent such as that of the VTS.

Table 1. AIS message format - (1) Dynamic Data

(Own ship)

$AIAOD,iiiiiiiii,rrr,llll.llll,a,yyyyy.yyyy,a,sss.s,ccc.c,hhh,hhmmss.ss,ABCDEN*hh<CR><LF>

(n) 1 2 3 4 5 6 7 8 9 10 11

(Other ship)

$AIARD,iiiiiiiii,rrr,llll.llll,a,yyyyy.yyyy,a,sss.s,ccc.c,hhh,hhmmss.ss,ABCDEN*hh<CR><LF>

(n) 1 2 3 4 5 6 7 8 9 10 11

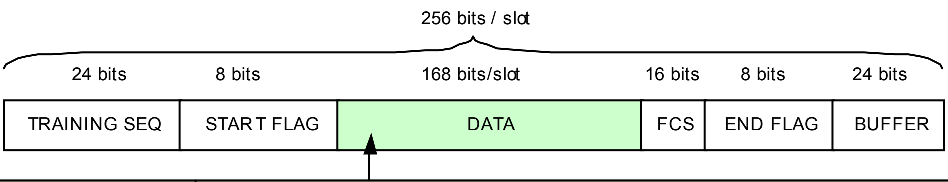
(n)	format	item	contents
1	iiiiiiiii	MMSI number	10 digits MMSI number(integer)
2	rrr	yaw rate	accuracy[unit]: 1[degrees/min] limits: +-127[degrees/min]
3	llll.llll	latitude	accuracy[unit]: 1/10000[minute]
4	a	latitude direction	N: north, S: south
5	yyyyy.yyyy	longitude	accuracy[unit]: 1/10000[minute]
6	a	longitudinal direction	E: east, W: west
7	sss.s	speed over ground	accuracy[unit]: 1/10[knot], limits: 0.0～102.4
8	ccc.c	course over ground	accuracy[unit]: 1/10[degrees], limits: 0.0～359.9
9	hhh	heading	accuracy[unit]: 1[degrees], limits: 0～359
10	hhmmss.ss	time stamp	GMT at the fixed timing of position, speed, etc.
11	ABCDEN	parameter flags	
	*hh	check sum	

Table 2. AIS message format - (2) Navigation Data

$AIVSD,iiiiiiiii,tt,dd.d,mmddhhmm,c,k--k,x*hh<CR><LF>

(n) 1 2 3 4 5 6 7

(n)	format	item	contents
1	iiiiiiiii	MMSI number	10 digits MMSI number(integer) ; of target ship (input), of own ship (output)
2	tt	ship type and cargo	according to ITU-R M.825
3	dd.d	draft	accuracy[unit]: 1/10[m], limits: 0.0～25.5
4	mmddhhmm	planned arrival time	planned arrival time at destination
5	c	receive channel #	0: own、A: channel 1, B: channel 2
6	k--k	destination	ASCII characters、max. 20 characters
7	x	status	0: sailing, 1: anchored, 2:Not under command、 3:Restricted maneuverability
	*hh	check sum	



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 4. The Message Structure of the AIS Communication Packet.

4. TRAFFIC CONTROL WITH AIS COMMUNICATION

4.1 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. Figure 3 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. On the other hand, an independent VTS agent joins the SEATRAS. It can also gather the information of the ships within selected areas through AIS communication. The VTS agent is equipped with a collision avoidance module that calculates the risk of the collision among sailing ships within each area, gives order to modify original passage plans of the respective ships. This module enables us to develop and verify new collision avoidance algorithms. The extension of the function of the module gives control for safety at an intersection.

4.2 AIS Communication

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 comprises 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 passage plan. Figure 4 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 4.1, 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.

4.3 Simulation of AIS in SEATRAS

The AIS is realized on the VHF Data Link (VDL). Each AIS message basically occupies one slot, 28 milliseconds, on the VDL. In the SEATRAS, major two types of AIS messages are simulated; one is a type of a static navigation data including an identity and a passage plan, the other is a type of a dynamic data including position, velocity and yaw rate. (Table 1 and Table 2) Each ship puts the two types of the messages at respective intervals as the UDP broadcast. The VTS agent gets these messages and selects target ships according to each ship's position data and area definitions.

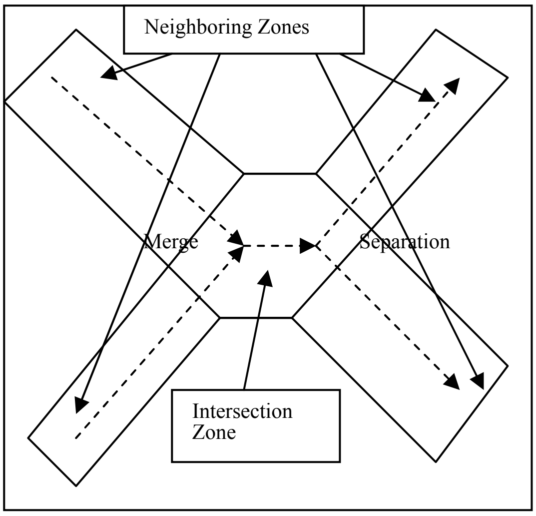


Figure 5. Merge and Separation

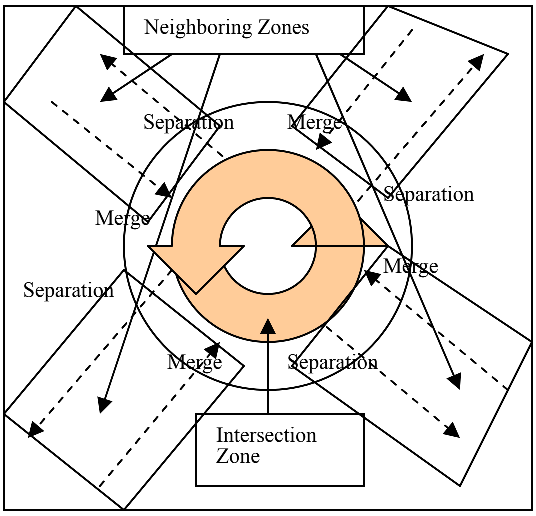


Figure 6. Rotary System

4.4 Control at Intersection

A weak control for safety at an intersection can be achieved with time control orders to large ships and other ships without easy control performance to enter the intersection zone. Other ships should avoid collision danger by themselves. In case of the simple intersection "merge and separation" tactics are effective, which avoid actual crossings like a rotary system on a road intersection. (Figure 5) There also exists an intersection between bi-directional traffic. The extension of the "merge and separation" tactics to the actual rotary system solves an intersection between bi-directional traffic. (Figure 6)

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 comprises 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. The VTS agent joins the SEATRAS and gathers information about ships within an intersection zone and neighboring zones through AIS communication. A simple tactics, "merge and separation", is proposed for a single intersection. A rotary system like a road intersection is also effective on a complex intersection between bi-directional traffic. SEATRAS realizes AIS simulation, which enables an area traffic control especially at an intersection. A weak control for safety traffic at an intersection can be achieved with these tactics because of low control ability in ship motions.

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